SCIENTIFIC AND PRACTICAL RESEARCHES IN LAPLAND ARRANGED
BY LUOSSAVAARA-KIIRUNAVAARA AKTIEBOLAG

GEOLOGY OF THE KIRUNA DISTRICT

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IGNEOUS ROCKS AND IRON ORES
OF
KIIRUNAVAARA, LUOSSAVAARA AND TUOLLUVAARA

BY

PER GEIJER

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KUNGL. BOKTRYCKERIET. P. A. NORSTEDT & SÖNER
1910

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Addendum

p. 74. The location of the outcrops shown in fig. 22 in relation to the rocks shown on the map in the scale of 1: 8000 is obtained by comparing the direction of the base line and the figures on it, giving the distance in meters from Nokutusjärvi, on the figure and the map respectively.

Introduction.

The region examined by the writer comprises the two ore mountains Kiirunavaara and Luossavaara and the continuation towards the sides and northward of the igneous rocks forming their slopes, further on, the ore mountain Tuolluvaara and some exposures located chiefly north of the latter and consisting of rocks more or less closely related to the ore-bearing ones. The object of the work was to make an exhaustive analysis of the petrographic characters of the igneous rocks and ores in question, and to explain the mutual relations of the different rock varieties as well as their relations to the ores. In this way one might expect to get a better insight into the mode of origin of the iron ores of the region. The ore problem is naturally the most interesting one in this region, but there are also, in the writer's field of work, as well as in the neighbouring regions, other phenomena of great interest.

The examinations having shown that the rocks in question represent relatively few eruptions and, as a rule, still have both their original structure and composition, the greatest part of this paper will consist of purely petrographic descriptions, the microscopic characters being most exhaustively treated on account of the fine grain of the rocks. The wish to give the very completest possible account of the rocks and ores has necessarily made this paper longer than is desirable from other points of view. In order to make the study of it more easy, the theoretical conclusions have chiefly been brought together in separate chapters.[1] Features, which evidently are of special importance for the solution of the ore problem, have always been described very minutely, as for instance the magnetite-syenite-porphyry, the dikes of magnetite and apatite, and the ore bodies.

The two districts, Kiirunavaara-Luossavaara and Tuolluvaara, are treated separately, the rocks of the former being described chiefly in chronological order. The syenite group composing the western slopes of Kiirunavaara and Luossavaara (i. e. the foot wall of the main ores), which is younger than the Kurravaara conglomerate, is exposed within five different regions: Kiirunavaara, Luossavaara, Valkeasiipivaara, between Luossavaara and Hopukka, Hopukka and

[1] An exception has been made only for some rather small sections, which are treated most appropriately in connection with the descriptions, as »Origin of the apatite dikes» and others.

Välivaara. To these regions one might possibly add a small area on Pahtosvaara, whose porphyries, studied by SUNDIUS, show great similarities to those of Kiirunavaara. Though the rocks within these different regions are very closely related to one another and probably — with the exception of some quantitatively subordinate dike rocks — represent different part of one single, enormous effusive body, it has seemed to the writer to be suitable to treat each area of outcrops separately. To treat the dike rocks of Kiirunavaara together with the other syenite rocks of the mountain may be an inconsistency, but is surely the most suitable manner of proceeding. As to Hopukka—Välivaara, where exposures are scant and the geological conditions seem to be rather complicate, each exposure or group of exposures has been treated separately, which manner of proceeding gives a rather objective view of the case.

The quartz-bearing porphyry, on the other hand, permits a more simple method of treatment. Its eastern border and the lowest parts of the Hauki complex are described together, in the same way — and for the same reasons — as the porphyries of Hopukka and Välivaara. The arrangement of the rest of the description will surely not require further explanations.

The relations between the two porphyry districts. As is shown by the maps and sections, the dip within the Kiirunavaara—Luossavaara district is always steeply easterly, by and by growing more level towards the south. In the Tuolluvaara district there are no sedimentary rocks, but the mode of occurrence of the porphyries on Sakaravaara makes it probable that the beds are lying almost horizontally. It is doubtful, whether the eastern district is to be regarded as an immediate continuation of the western one — in this case the Hauki complex should evidently represent a strongly pressed syncline — or if it has been separated from the latter by some kind of faulting processes. The last-mentioned eventuality seems, however, to be the most probable one. It is almost out of question, that these eastern porphyries should represent a later break in the sedimentation and be younger than the Hauki complex.

Nomenclature etc. BÄCKSTRÖM [42][1] called the porphyries surrounding the ores keratophyre and quartz-keratophyre, evidently wanting to emphasize their character of soda rocks. Other authors have used the same name, even the present writer [14]. That I do not use it in this work is due to the fact that the meaning of the term keratophyre since BÄCKSTRÖM's description has changed considerably and is now rather vague. After the approbation of the term »potash-keratophyre», keratophyre is no longer synonymous with soda-syenite-porphyry. Moreover there are among the keratophyres several chemically different types of rock. Before, ROSENBUSCH regarded most of them as alkali rocks, but in the last edition (of 1910) of his »Elemente der Gesteinslehre», he places them among the lime-alkali rocks. Thus I think it most appropiate here to drop the term keratophyre and to use the term *syenite-porphyry* and, for the rather much quartz-bearing variations, *quartz-porphyry*. ROSENBUSCH has, it is true, limited the term »syenite-porphyry» to dike rocks only, but as the por-

[1] Figures in [ ] refer to the numbers in the list of works cited (p. 274).

phyries described here, though being effusive, pass into true syenite and thus often structurally resemble dike rocks, the extended use of the term will probably not cause any confusion.

The quartz-bearing porphyries cannot be called anything else than quartz-porphyry; quartz-syenite-porphyry being too long, though, it is true, more correct with regard to the predominant rocks rather poor in quartz. (Porphyries with quartz phenocrysts occur only on Sakaravaara and as dikes on western Kiirunavaara).

As to the terms *structure* and *texture*, I have used only the first mentioned one for both phenomena, this from the reason that different authors use these terms in a quite contradictory sense (e. g. American writers on one hand and Germans on the other).

The term *vein* is here used of small *dikes* without having any genetical signification, and, according to the usual custom, of quartz veins and similar phenomena quite regardless of their dimensions.

Hematite is used for specular iron ore. As the *index of refraction* of the minerals often is given compared to that of Canada balsam, I ought to point out that, in the kind of balsam used, it is always lower than that of both the rays of the quartz.

* * *

The field work is based principally on a geological map by HJALMAR LUNDBOHM, who has also placed at the writer's disposal his note books and his experience about the geology of the district. The above mentioned map, accompanying this paper, has been completed by N. ZENZEN, R. LOOSTRÖM, N. SUNDIUS and the writer, and also by the mining engineers H. NATHORST and H. KRÆPELIEN.

All the expenses for the field work, for analyses, printing etc. have been paid by LUOSSAVAARA-KIIRUNAVAARA AKTIEBOLAG.

The writer wishes to express his most sincere thanks to Professor A. G. HÖGBOM, of Uppsala, who has assisted me in many different ways during my geological studies at the university and who has given me many useful hints especially with regard to the way of disposing the work in question, as well as to Professor H. BÄCKSTRÖM of Stockholm, and my fellow-students at Kiruna N. ZENZÉN, N. SUNDIUS and R. LOOSTRÖM. The analyses, except the four quoted by LUNDBOHM and BÄCKSTRÖM, in 1898, have been made by R. MAUZELIUS and assistants at the laboratory of the Geological Survey of Sweden; most of the thin sections used have been made by A. R. ANDERSSON, at the geological institute of the university of Uppsala. This have been to a great advantage to the work. For help with the taking of photographs of the thin sections and hand specimens I am indebted to O. TENOW, Phil. Lic., of Uppsala.

THE KIIRUNAVAARA-LUOSSAVAARA DISTRICT.

Rocks of the syenite group.[1]

Kiirunavaara.

Kinds of rock.

The rock in the westernmost parts of Kiirunavaara is a medium-grained syenite, to the east passing through more fine-grained, porphyritic phases into true syenite-porphyries[2] with very fine-grained or dense groundmass and often having a peculiar nodular structure, and showing strong signs of consanguinity with the syenite. These porphyries form the greatest part of Kiirunavaara west of the ore. Younger than this geogically uniform mass of syenitic eruptives is a series of dikes of a rather similar syenite-porphyry. There also occurs, but only in very small quantities, a fine-grained, dark dike rock, as regards the age probably to be placed between the two series just mentioned. Younger than the whole syenitic group is a granophyric quartz-porphyry, of which rock there are one big, and some small dikes.

For the petrographic description the kinds of rock have been divided into: syenite, fine-grained syenite, syenite-porphyries, dikes of dark syenite, dikes of syenite porphyry. The boundaries between the first two groups and between the second and the third one must be quite arbitrary. Most advisable would be to draw the first boundary line where the syenite begins to grow porphyritic, which is the case when the average size of the feldspars is about 1 mm. The other line of demarcation should be drawn when this value is about 0,3 mm.

[1] As to the distribution of exposures, see the introduction.

[2] By way of distinction from the dike porphyries mentioned below, these rocks may be called »older» porphyries.

Syenite.

Macroscopic characters.

The syenite is an altogether massive rock, without any schistosity. It is rather variable as regards composition, colour and size of grain, but the changes are as a rule slow and regular. Very sudden alternations occur only on the borders to the porphyritic phases.

The predominating constituent is always feldspar in the form of generally somewhat elongated individuals, showing almost rectangular sections. The size varies from 5 to 6 mm in diameter in the coarsest varieties to 1 mm on the border to the porphyritic phase. The colour of the feldspar is also variable: yellowish white, pale brown, gray, grayish purple or reddish brown, in the pits dug most westernly it is grayish yellow, which, as is shown by the microscopic examination, depends upon the quantity of epidote resulting from alteration. Beside the feldspar there is seen a pale- or dark-green mineral of the pyroxene- or the amphibole-group. It occurs in short prismatic individuals of a smaller size than the feldspars.

Black grains of magnetite are most often seen, and the rock is sometimes composed only of magnetite and feldspar. Titanite is common, biotite rather rare.

It is characteristic of the structure that the dark minerals are concentrated between the feldspar individuals.

Hornblende and sometimes also titanite occur in the shape of thin, irregular veins, only reaching a width of 1 or a few mm. Small fissures are filled with quartz. About 1 cm wide, somewhat ramified veins of dense, bluish black magnetite, with distinct contacts with the syenite, are only seldom seen.

In one place there occur in the syenite areas a few dm in diameter of a dense, almost black, schlieric rock very rich in magnetite. The outlines of these areas towards the syenite are always very distinct. They are very probably inclusions of a foreign rock. In the outcrops of syenite in the northwestern part of Kiirunavaara there are some fragments of a fine-grained, grayish green or black rock, sometimes even 1 dm long, the outlines of which are rather vague, indicating that some melting has taken place there. Similar fragments are very abundant in the morainic

boulders of the syenite, which occur in the southernmost parts of the mountain, around Jägmästarn. There are also seen boulders of the fine-grained rock, with dikes of syenite.

Microscopic characters.

By the microscopic examination, compared with the two analyses, a much better idea of the relative quantities of the different minerals is of course obtained than can be acquired by studies only in the field or of hand specimens. Feldspar is always predominating and amounts to 70 or 75 per cent, more seldom to about 80 per cent. Augite and its alteration product, uralite, vary from a few to about 15 per cent in all, as a rule they make up about 10 per cent of the rock. Magnetite also varies a good deal, it constitutes from only a few per cent up to more than 15 per cent. Titanite generally amounts to at least 3 or 4 per cent, quartz, apatite, biotite and zircon are less important, but each of them (except the zircon) can nevertheless amount to at least 2 per cent.

With the exception of the products of alteration, no other mineral is of any account as regards quantity.

Feldspar. Free plagioclase and potash-feldspar are as a rule not found, all feldspar being *microperthite*, composed of a plagioclase component and another component with a considerably lower single and double refraction. The former is nearly always predominant. Polysynthetic twinning (albite law) is very common in it. The lamellæ are most often regular, sometimes broad, sometimes very thin. The lamination, especially the one with broad lamellæ, is often confined to the central parts of the individual, while the peripheric ones are optically homogeneous or show a very thin lamination, often combined with such a one according to the pericline law. The cross-twinning thus formed is more irregular than the one common to microcline. Nevertheless one would perhaps at first sight consider the phenomenon as a frame of microcline around a plagioclase. A closer examination shows, however, that the centre and the periphery have about the same double refraction and that their single refractions, compared[1] to the intergrown potash-feldspar, are almost, if not quite, alike. Epidote is sometimes amply developed in the central, broadly laminated parts, but it is not seen in the cross-twinned frame around them. The calculation of the analyses shows the composition of the plagioclase to be about Ab_{92} An_8. But it is probable, that part of the CaO and Al_2O_3 which is allotted to the anorthite actually enters into the augite molecule, for which reason it may be supposed that the plagioclase often is almost pure albite. With this agree the optical properties, which are determined in slides of the rock or of separated grains, in the latter case cut parallel to the principal cleavage planes. In such a slide parallel to the pinacoid (001) the extinction angle $\mathfrak{a}$: a was a little more than 3°. Nonlaminated sections show a very good cleavage in one direction, the extinction angle measured with reference to that system amounts at the most to 20°. A positive bisectrix at right angles to the section or somewhat oblique is seen in convergent light. These sections are evidently cut parallel to the pinacoid (010). The index of refraction differs very slightly from that of the surrounding Canada balsam.

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[1] After BECKE's method.

The potash component sometimes shows the cross-twinning of the combined albite and pericline laws, which is characteristic of microcline. The perthitic stripes are not very regular and vary considerably in width. In sections parallel to the pinacoid (001) they run pretty much at right angles to the albite lamellæ, in sections parallel to (010) they form an angle of about 70 to 74° with the cleavage cracks, which run parallel to (001). The stripes of the latter sections are more regular than those of the former. The microcline laths thus appear to be parallel to the Murchisonite face, which is a quite common perthitic law.

The microperthite individuals are often simple twins, the composition plane is (001), parallel to which face they are elongated. They consequently follow the Mannebach law. The boundary between the two halves of the twin is quite rectilinear or somewhat jagged.

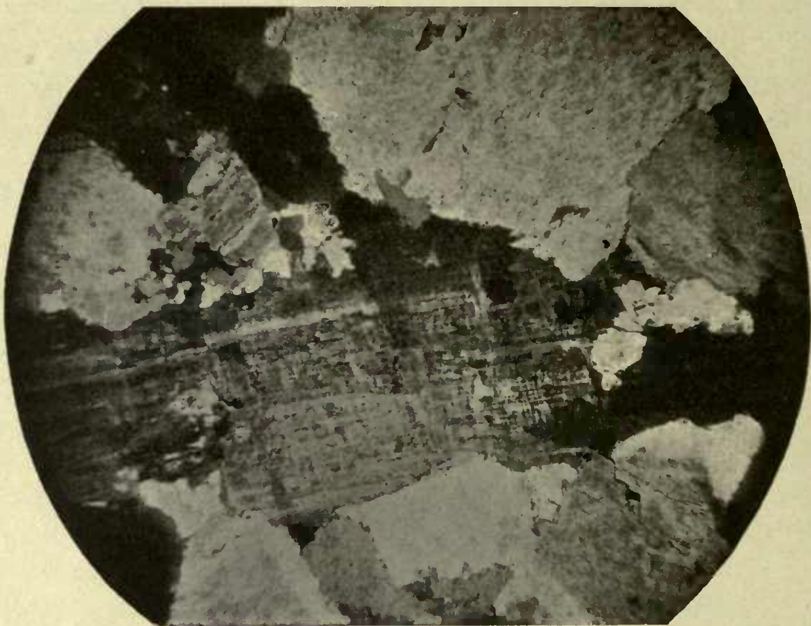

Fig. 1. Feldspars in syenite, northwestern Kiirunavaara. Nic. +. Magn. 35 times. In the centre of the figure a finely cross-twinned albite, surrounded by microperthite individuals of the usual habit.

In one slide there is no microperthite. The feldspar is optically homogeneous or polysynthetically twinned according to the albite law, with extremely thin lamellæ, besides there are now and then some according to the pericline law. Even at a 400-fold magnification this twinning is often seen only as a faint shade. It is very probable that this feldspar is a soda microcline. (Bröggers nomenclature, i. e. anorthoclase Rosenbusch.) The same is evidently true regarding the above mentioned cross-twinned frame surrounding a broadly lamellated centre. This soda microcline shows the Mannebach twins and other features characteristic of the common feldspar of our syenite.

To the writer it therefore seems very probable that the microperthite is of a secondary development, the original feldspar being an isomorphous mixture of microcline, albite and very subordinate anorthite molecules.

Free plagioclase, presumably albite, occurs very seldom, and in the shape of small grains between the microperthites. Free microcline is also occasionally found.

As seen by the Mannebach twins, the microperthite crystals are often tabular parallel to the pinacoid (001). Other individuals are more isometric. The outlines of the different grains are very irregular, sinuous and jagged.

The feldspars are as a rule very little altered;[1] the most common alteration product is muscovite (paragonite?) in the shape of small flakes, or epidote in small crystals or rounded grains. As stated above, the latter occurs chiefly in the central parts of the crystal, which were probably originally richer in CaO than the peripheric ones.

The *quartz* has all the optical properties which are characteristic of this mineral and sometimes shows slightly undulatory extinction. When occuring very sparingly it generally forms small grains (0,1 to 0,3 mm in diameter) or groups of grains, lying between the feldspars. When amounting to at least a few per cent, it is generally intergrown with the feldspars. In the quartz areas, which reach up to 1 mm in diameter, there are then often single angular, generally elongated feldspar grains with the same optical orientation as the immediately surrounding individuals of the same mineral. The intergrowth is thus much less complicate than a usual graphic one.

Augite and *uralite.* The augite is colourless or pale green, without any visible pleochroism. It shows the usual, perfect prismatic cleavage and is optically positive. The optical orientation is: $\mathfrak{b} = b$; $\mathfrak{c} : c =$ about 45°. It is accordingly a diopsidic augite; the amount of the double and single refraction corresponds also very well to this. There are often seen twins following the usual law, twinning plane and composition plane is (100). It often occurs as short, badly idiomorphic prisms between the feldspars; but it is also found in a very peculiar intergrowth with them. This intergrowth is seen especially in the rock in one of the dug pits on northwestern Kiirunavaara, but is also found in other places, though less marked. The augite then forms relatively small grains, 0,1 to 1 mm in size (the feldspar grains reach a size of 1 to 3 mm in this slide), the outlines of which are sometimes straight or a little curving, sometimes very sinuous and forming all kinds of small projections. Throughout areas of a size of 1 to 2 square mm in the slide, all such grains have the same optical orientation. See figs. 2 and 3.

From this special form there are transitions to continuous, but much ramified individuals of the same size as these groups. It is therefore probable that these, from one another isolated grains have some connection in another plane than that of the slide. Each augite individual is intergrown with one or several feldspars and continues also through the groups of quartz between them, but then always following the borders between the different quartzes. The structure is thus neither ophitic nor poikilitic, but rather granophyric (graphic); it has some likeness to the structure of the titanite, which will be described further on.

The augite is more or less transformed into uralite. There are slides in which this alteration scarcely can be discovered, but generally there are only some inconsiderable remnants or nothing at all left of the original augite. The uralite is a common hornblende (»Gemeine Hornblende» Rosenbusch), with $\mathfrak{b} = b$; $\mathfrak{c} : c =$ about 20°. The pleochroism is rather weak, with the following colours:

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[1] Here we leave the development of titanite out of consideration.

$\mathfrak{a}$ — pale yellowish green, $\mathfrak{b}$ — brownish green; $\mathfrak{c}$ — bluish green; absorption $\mathfrak{b} = \mathfrak{c} > \mathfrak{a}$. The first stage of the uralitisation is the appearance of small hornblende needles on the outside of the augite, with their c-axes parallel to that of the former. (See fig. 2.) The alteration begins moreover at the periphery and continues towards the centre, preferably following the cleavage cracks. It is noticeable that no minerals are found which can be looked upon as byproducts, the uralitisation might therefore be considered as almost quite a paramorphose.

The uralite mostly occurs in the form of rather irregular prisms, lying between the feldspars. From this form there are also transitions to an intergrowth

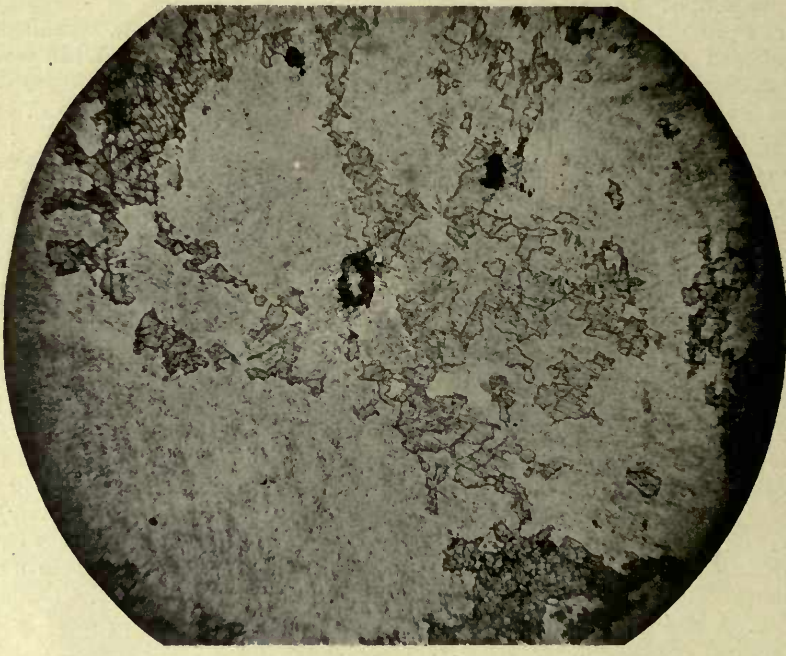

Fig. 2. Skeleton augite individuals in syenite, northwestern Kiirunavaara. Ord. light. Magn. 35 times. Note the thin hornblende needles growing out from the augite!

resembling that of the augite. The mineral is now compact, now fibrous, the latter especially towards the ends of the individual. Twinning according to the general law often occurs (twinning plane is (100).

As inclusions occur especially magnetite, in some uralites forming branchy groups of crystals. Titanite often occurs in the form of lumps with long points, which follow the cleavage cracks. It seems to be of secondary origin. Secondary is probably also the biotite, which occurs along the cracks, and certainly a pale green chlorite which sometimes occurs in great quantities.

Hornblende. In one slide from the most northwestern part of the mountain there occurs neither augite nor uralite, but instead of these minerals a hornblende of indisputably primary origin. It has $\mathfrak{b} = b$; $\mathfrak{c} : c$ is measured in one case to be 18°, which is a minimum value. The pleochroism is:

$\mathfrak{a}$ — pale yellowish green; $\mathfrak{b}$ — olive green; $\mathfrak{c}$ — bluish green; absorption $\mathfrak{b} = \mathfrak{c} > \mathfrak{a}$. It differs from the uralite principally in the bluer colour of $\mathfrak{c}$. The

birefringence is the one typical of common hornblende. The mineral forms short and thick prisms without idiomorphism, generally lying between the feldspars. In a mesostatic titanite individual there are enclosed some idiomorphic individuals showing the prism faces (110). One of these is a twin, the twinning plane is (100).

The syenite containing this primary hornblende encloses a fragment of grayish green, fine-grained rock of the kind that is described on p. 2. This kind of rock also contains similar hornblende, but in much smaller grains, and it is possible that its origin in the syenite just here depends on the melting and the recrystallization of the borders of the fragment.

Fig. 3. Same as fig. 2, but nic. +. Shows the common orientation in the group of augite particles in the centre of the figure, and the habit of the microperthitic intergrowth of the feldspar.

Titanite. This mineral is not wanting in any slide of the syenite. It is very probable that the titanium percentage of the rock almost wholly enters into the titanite. In thin sections it is pale brown or yellowish brown with very slight pleochroism. Thin twinning lamellæ, parallel to the cleavage cracks, are often seen.

With regard to the shape of the titanite individuals, they can be divided into three types. They occur: 1) as mesostasis, filling the angular spaces between the feldspar and quartz grains; 2) in skeleton-formed individuals, branching out in irregular formations, or as a fine network; 3) with a combination of the characteristics of the first two types.

The first type is rather rare. The shape of the titanite is altogether dependent on that of the other minerals, especially the feldspar, but even the quartz. (See fig. 4.) The idiomorphic crystals of primary hornblende enclosed in the titanite shows that the hornblende too is older. Such titanite individuals can reach a diameter of 5 mm. In their relations to the feldspars they are

quite similar to the augite in diabases or other rocks with ophitic structure. As far as I know, titanite with this singular structural form has been found before only in two places, in the Pyrenees [34], and in Stockholm [13]. The rock is in both cases a granite.

The second type is beyond comparison the most common one. Like the former it is distinguished by the total absence of idiomorphism, but differs from it by the fact, that the shape of the titanite never is determined by the other minerals; it generally occurs within them, especially in the feldspars. Its relations to the augite (uralite) and the hornblende have been described above. The titanite individuals occuring in the feldspars are of very varying shape. They are sometimes rounded lumps, sometimes lobate or shaped as extremely

Fig. 4. Titanite in syenite, northwestern Kiirunavaara. Nic. +. Magn. 35 times. Shows titanite of the first type, occuring between the microperthite crystals. Some magnetite (black) is associated with the titanite. The areas of the latter are optically orientated in the same way.

extended branches, skeleton-like and sometimes form a very fine network. Titanite grains, which in the slide are isolated from each other, are often found to have the same optical orientation. This phenomenon can probably be explained in the same way as the corresponding one in the augite. Such titanites very often extend over many different feldspars. In fine-grained syenite there has been noticed one case when an individual extends over an area about 2 mm in diameter and is intergrown with as many as 10 feldspars. Still larger groups occur, and their size has nothing to do with that of the feldspars.

The third type is rarer than that above described, but it is more common that the first one. It is a transition form between these two, as has already

been stated. Its most distinguishing feature is accordingly, that the shape of the titanite sometimes is determined by the other minerals, but that from these rectilinear titanite areas irregular little outgrowths now and then branch off into the surrounding feldspars.

Nearly all apatite crystals are wrapped in a thin covering of titanite, which now and then has also eaten its way along the irregular basal cleavage cracks and cut the prism into isolated grains. Fig. 5 illustrates this phenomenon; the figure in the middle is a cross-section, the others are longitudinal sections. The covering may be much thicker than is shown in the figure.

The titanite often includes magnetite. As this happens with most minerals in this rock, it is no cause for believing the magnetite to be titaniferous. But there are occasionally seen broad lamellæ of an opaque mineral, forming an angle of about 55° and lying in titanite. This mineral is perhaps ilmenite.

Apatite. This is one of the first crystallized minerals and occurs enclosed in nearly all others, especially in the feldspars. Its general habit is prisms reaching a size of 0,2 to 1 mm, more seldom up to 8 mm. Crystals in the

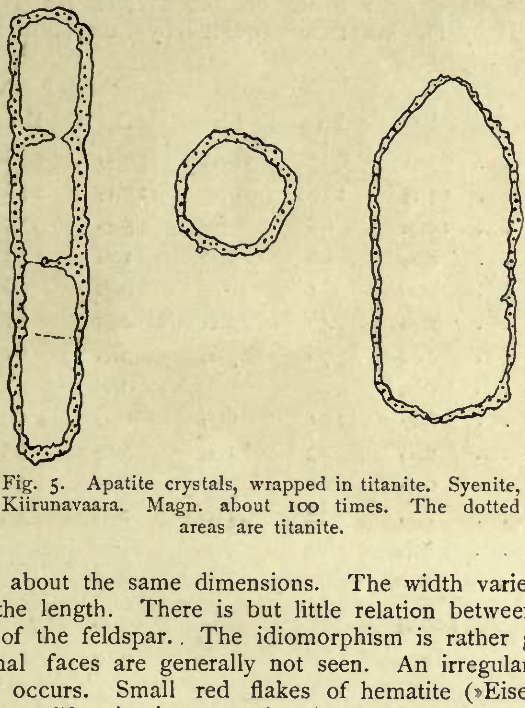

Fig. 5. Apatite crystals, wrapped in titanite. Syenite, Kiirunavaara. Magn. about 100 times. The dotted areas are titanite.

same slide have about the same dimensions. The width varies from one-third to one-tenth of the length. There is but little relation between the size of the apatite and that of the feldspar. The idiomorphism is rather good in the prism zone, but terminal faces are generally not seen. An irregular parting parallel to the pinacoid occurs. Small red flakes of hematite (»Eisenglimmer») often occur as inclusions. The titanite cover has been described above.

The *biotite* is nearly uniaxial, with the pleochroism: $\mathfrak{a}$ — pale yellowish; $\mathfrak{b} = \mathfrak{c}$ — brownish green. It forms small flakes with a diameter of generally 0,1 to 0,2 mm and occurs in feldspar and hornblende. In the latter case it is probably a product of alteration.

The *magnetite* sometimes occurs as small crystals about 0,1 mm in size, scattered throughout the whole mass of the rock. As a rule, however, it is concentrated in lumps with jagged outlines showing them to be aggregates of crystals. These lumps reach a size of 0,1 to 1 mm. They seldom occur within the feldspars, but are found on the border between them. It also hap-

pens that they, instead of having the usual jagged outlines, are bordered by straight lines, which reminds us of the first type of the titanite and very clearly shows that the mineral has crystallized later than the feldspar.

The probable occurence of *ilmenite* in a very small quantity has already been stated.

The *zircon* occurs as short crystals (about 0,2 mm in size) with prismatic and pyramidal faces and a very good idiomorphism. They are often surrounded by a zone of red pigment.

Pyrite occurs only very seldom, as crystals peripherically altered to red oxide of iron.

The alteration products — muscovite, epidote and chlorite — are described above.

Chemical characters.

Two analyses have been made on the syenite, No. I for this work by G. Nyblom, No. II by H. Santesson (quoted by Lundbohm and Bäckström.)

	I	I a	I b	II	II a	II b
SiO_2	53,31	883	59,06	59,57	986	65,38
Al_2O_3 . . .	14,19	139	9,29	15,14	148	9,82
Fe_2O_3 . . .	10,92	68	—	5,50	35	—
FeO	4,29	60	13,18	1,62	23	5,97
MnO	0,06	1	—	0,36	6	0,41
MgO	1,96	49	3,25	2,46	61	4,04
CaO	4,38	78	5,23	3,42	61	4,04
BaO	0,04			n. d.		
Na_2O . . .	6,27	101	6,74	6,13	99	6,53
K_2O	2,19	23	1,55	3,27	35	2,30
H_2O+ . . .	0,40	22	—	0,57	32	—
TiO_2	1,80	22	1,50	1,82	23	1,51
P_2O_5	0,43	3	0,20	—		
S	0,01			n. d.		
	100,25			99,86		
H_2O-[1] . .	0,15			n. d.		

No. I Syenite, W of Geologen, Kiirunavaara.

No. I a Molecular proportions of No. I, multipl. by 1000.

No. I b As above, calculated on a sum of 100, free from H_2O, all Fe as FeO.

No. II Syenite, Kiirunavaara.

No. II a see No. I a.

No. II b see No. I b.

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[1] This figure gives the percental loss of weight of air-dried material when heated to 110°.

American system.

No. I.		*Norm.*			
Quartz	SiO_2	0,42	Q	0,42	Sal 70,67
Orthoclase	$K_2O . Al_2O_3 . 6\ SiO_2$	12,86	F	70,25	
Albite	$Na_2O . Al_2O_3 . 6\ SiO_2$	53,21			
Anorthite	$CaO . Al_2O_3 . 2\ SiO_3$	4,18			
Diopside	$CaO . SiO_2$ 5,70; $MgO . SiO_2$ 4,94	10,64	P	11,10	Fem 29,07
Wollastonite	$CaO . SiO_2$	0,46			
Magnetite	$FeO . Fe_2O_3$	9,05	M	17,04	
Hematite	Fe_2O_3	4,64			
Ilmenite	$FeO . TiO_2$	3,35			
Apatite	$3\ CaO . P_2O_5$	0,93	A	0,93	

Sum 99,74 + H_2O etc. = 100,24.

Class 2 Dosalane, Subclass 1 Dosalone, Order 5 Germanare, Rang 1 Umptekase, Subrang 4 *Umptekose*

No. II.		*Norm.*			
Quartz	SiO_2	2,77	Q	2,77	Sal 78,39
Orthoclase	$K_2O . Al_2O_3 . 6\ SiO_2$	19,57	F	75,62	
Albite	$Na_2O . Al_2O_3 . 6\ SiO_2$	52,15			
Anorthite	$CaO . Al_2O_3 . 2\ SiO_2$	3,90			
Diopside	$CaO . SiO_2$ 5,47; $MgO . SiO_2$ 4,74	10,21	P	11,63	Fem 21,15
Hypersthene	$MgO . SiO_2$	1,42			
Magnetite	$FeO . Fe_2O_3$	1,39	M	9,52	
Hematite	Fe_2O_3	4,64			
Ilmenite	$FeO . TiO_2$	3,49			

Sum 99,54 + H_2O etc. = 100,13.

Class 2 Dosalane, Subclass 1 Dosalone, Order 5 Germanare, Rang 1 Umptekase, Subrang 4 *Umptekose.*

Osann's system.

	s	A	C	F	a	c	f	n	k
I	60,56[1]	8,29	1,00	20,66	5,5	0,5	14	8	1,11
II	66,89	8,83	0,99	13,48	7,5	1	11,5	7,4	0,89

[1] The low percentage of P_2O_5 has not been considered. (Compare 49 I p. 354.)

The low percentage of anorthite has already been pointed out at the de scription of the feldspars. In spite of its never going down as far as to nought, the rock is evidently chemically near akin to the real »Alkaligesteine» of ROSENBUSCH, as appears from its place in the first rang of the american system and in »Erste Vertikalreihe» in that of OSANN.

The norm agrees very well with the mode, with the exception of the mode of occurence of the titanium. In the norm this is allotted to FeO to form ilmenite, but in reality it doubtless enters almost totally into titanite. The group M is therefore in reality composed mostly of magnetite and is somewhat smaller than has been calculated.

Discussion of the structure.

The relations between the femic minerals and the feldspar are very remarkable. The magnetite, which as a rule is among the very first minerals to crystallize, often occurs in a manner, that beyond doubt shows it to be younger than the bulk of the feldspar. The augite, and consequently also the uralite, occur in skeleton-shaped individuals, intergrown with the feldspar. This structure has been characterized above as granophyric and is indicative of an almost simultaneous crystallization of the two components. Such phenomena are very seldom seen in any normal igneous rocks but the alkali- and the nepheline-syenites, whose aegirine and arfvedsonite occur in similar shapes. [52, II: 1 pp. 197 and 201.] Somewhat equal structures are found in some orbicular granites [5.]

Concerning titanite with the same habit as the 1:st above described type, the writer [13] has pointed out that the mineral might be of secondary origin and developed trough the replacement of another, before existing mineral, or fill miarolitic cavities. The examination of the titanite (1:st type) occuring in our syenite has shown that it very probably filled the spaces between the feldspar but nevertheless must be regarded as a primary constituent of the rock. The 2:nd and 3:rd titanite types show, however, that the distance is not so very great between such a mode of formation and the first of the op. cit. proposed explanations.

BÄCKSTRÖM [42] has described allotriomorphic titanite in the plagioclase phenocrysts of the syenite-porphyries of Kiirunavaara, he regards it as pneumatolytically new-formed at the cost of the CaO percentage of the plagioclase. The same interpretation is probably correct concerning the 2:nd type in the syenite. The 3:rd type, on the other hand, shows the olose connection between the two others and makes it quite clear that

the titanite must be considered as a relatively primary constituent of the syenitic rocks here.

The relations between the titanite and the apatite are also very remarkable. The titanite is evidently here new-formed, if possible even more obviously than in its relations to the feldspar, replacing the older mineral, the CaO percentage of which probably has entered into the titanite. Its occurence in augite and hornblende might also be explained in the same way.

As a conclusion may be said, that the titanite has been one of the last crystallizing components of the syenite and that it has partly been formed by the replacement of before existing CaO-bearing minerals, probably through the action of titaniferous solutions or vapours on the solidifying rock. Granted that these reactions take place at such an early stage, the lack of by-products at the »titanitisation» will be less astonishing

That I have dwellt on the titanite for so long is mostly due to the fact, that the above described phenomena are of importance for the comprehension of certain rather peculiar structural features in the porphyries, which on the other hand are material to the question of the mode of formation of the ore bodies.

Fine-grained, porphyritic syenite.

Distribution and macroscopic character.

This phase is a transition form between the syenite and the porphyries, and consequently occurs on the boundaries between the districts, where these two rocks are to be found. Small areas, which properly ought to be considered as belonging to this phase are also sometimes found in the syenite and in the adjacent porphyries. It is on the whole a form of secondary importance among the syenite rocks on Kiirunavaara.

It differs from the normal syenite only in being more fine-grained and in the tendency to porphyritic development of some feldspars. There are no distinct contacts with the normal syenite nor with the porphyries, but a very evident transition on the contrary has been observed in both directions.

The fine-grained syenite is generally of a grayish purple or reddish colour. On a weathered surface small and white single feldspar phenocrysts appear very distinctly.

Microscopic characters.

Even under the microscope the rock shows a great resemblance to the normal syenite. Feldspar is the predominating constituent. The phenocrysts often reach a length of 1 to 2 mm and appear as short rectangles. The idiomorphism, however, is not very good. Most often they show lamination (albite law), especially in the centre, where they are also somewhat altered to epidote. Microperthitic laths occur and are arranged in the same way as has been described in connection with the feldspar of the syenite. The small individuals which form the groundmass are often perthitic in the same manner, but may also be homogeneous. They often show a very thin lamination according to the albite law, often combined with a more irregular one at right angles to the former (pericline law). When only homogeneous feldspars occur in a slide, it appears to the writer as a reason for suspecting this very thinly laminated, often cross-twinned feldspar to be a soda-microcline (anorthoclase) of the same kind as has before been assumed concerning some feldspars in the normal syenite. The sections are often of a more elongated rectangular shape than in the syenite, sometimes they are sphærulitically arranged.

The augite and the uralite do not occur in complicated intergrowth with the feldspar, nor does the titanite occur as types 1 and 2; otherwise the structure is similar to that of the normal syenite. Fibrous amphibole is rather prevalent, being probably in part of uralitic origin, in part replacing the feldspar.

Special studies of the transition between the syenite and the porphyries.

That such a transition exists has been shown as early as in 1891 by LÖFSTRAND [43] and has been stated by LUNDBOHM and BÄCKSTRÖM as well [42]. As this question is of great importance to the interpretation of the geology of the district and moreover is difficult to settle, two profile lines, running nearly east and west, have been selected for the examination of details. These profiles are on the map seen as lines of crosses. The most northerly one is in its westernmost part composed of the series of dug pits, which has been mentioned several times. It also very well illustrates the variations of the syenite.

Profile No. I. Attempts were made to prolong this profile more to the west, but the writer was obliged to give them up on account of the thick morainic covering.

Beginning in the west.

Pit at *0 meters* In both pits the same rock, a medium-grained syenite
» » *80* » with grayish yellow feldspar, reaching a size of 1 to 3 mm, and much hornblende in short prisms.

Under the microscope the feldspar is seen to be altered to epidote to a large extent, but twinning according to the albite law is nevertheless seen. The hornblende is somewhat fibrous. Magnetite, biotite, titanite and apatite are present in small quantities.

Pit at *130 meters.* Grayish green syenite, more fine-grained than the former (the feldspars reaching a diameter of about 1 mm); some feldspars, which are somewhat larger, give the rock a porphyritic character.

This rock is the one before mentioned (p. 4) in which all the feldspars have characters resembling those of the soda-microline. Besides there occur hornblende, and more sparingly quartz, titanite, magnetite and zircon.

Pit at *150 meters.* Brownish gray syenite, medium-grained (feldspars reaching a size of about 1 to 3 mm).

Consists of microperthite, hornblende in skeleton-formed individuals, titanite, apatite and magnetite, all in a considerable quantity. Biotite and zircon more sparingly.

Pit at *185 meters.* Reddish syenite, of the same coarseness as that just mentioned, with a fair abundance of pale green augite.

The feldspar is microperthite, the augite is fresh and shows the above described peculiar intergrowth with the feldspar. Quartz is sparingly present.

Pit at *192 to 200 meters.* In the western half, syenite of the above described type. East of it a pale gray porphyry with phenocrysts of a green silicate and feldspar, the latter reaching a length of a few mm.

Close by the contact both rocks are much decomposed, but unaltered syenite and porphyry are found at a distance of about 2 dm from one another. From this may be assumed that the contact is quite distinct. It extends almost north and south.

Pit at *210 meters.* Syenite, like the one exposed at 185 meters, but with hornblende (uralite) instead of augite. The porphyry, being thus enclosed between syenite exposures and observed in almost actual contact with this rock, must be a dike rock.

Pit at *248 meters.* Syenite as above, but containing, contrary to the former, nearly unaltered augite in short prismatic individuals. Titanite is rather abundant, magnetite is more sparingly present.

Trench at *298 to 334 meters.* In this trench there is a transition from syenite to true porphyries. As far as to 319 meters the rock is a syenite of a light brown shade, somewhat more fine-grained than the one exposed at 248 meters. Its appearance is then suddenly altered: at 320 meters it is still more fine-grained with a few not very conspicuous feldspar phenocrysts; at 321 meters these characters are more pronounced,

and already at 322 meters it must be described as porphyry, of the same kind as the most usual types of the »older» syenite-porphyries of Kiirunavaara. At 324 meters the groundmass is much more fine-grained, and the feldspar phenocrysts reach a size of 2 to 3 mm. The rock further west shows about the same characters, but is in places more similar to the fine-grained syenite, e. g. at 358 meters. The porphyry dike No. 2 (see p. 42) is exposed in the eastern part of the trench. The transitions just described are *quite continuous*. The most important step is between 321 and 322 meters, for which reason this little section was a subject to a very careful examination.

Under the microscope as well the transition proves to be continuous. At 320 meters the rock is quite similar to the syenite with regard to mineralogical composition and structure, but the feldspars are only $0{,}5$ to $0{,}7$ mm in size, apart from the small phenocrysts. Besides it contains quartz, some hornblende, magnetite and titanite (1:st type). The rock exposed at 322 meters has a few phenocrysts of plagioclase with very subordinated microcline in perthitic intergrowth, they reach 1 to 3 mm in size and are badly idiomorphic. The feldspars of the groundmass resemble those of the syenite except with regard to their size, which is only $0{,}2$ to $0{,}5$ mm. Other constituents are hornblende, titanite and magnetite. The rock exposed at 327 meters differs from the above in the smaller size of the feldspars of the groundmass ($0{,}1$ to $0{,}3$ mm), and in the better idiomorphism of the phenocrysts.

The above described phenomena cannot be interpreted otherwise than as the syenite and the »older» porphyries being contemporaneous and phases of the same body of syenitic magma. They are absolutely irreconcilable to any interpretation of the syenite as a rock considerably older than the porphyries or as a younger intrusion in the latter.

Profile No. II, beginning in the west:

0 to 12 meters. Fine-grained, reddish gray rock with small feldspar phenocrysts, towards the east passing into a somewhat more coarse, grayish purple syenite with less developed porphyritic characters. Here and there are seen veinlets of hornblende, titanite and apatite, only a few mm wide.

A slide of the rock exposed at 0 meters shows rectangular feldspar phenocrysts reaching a size of 5 to 6 mm with very thin lamellæ according to the albite law, but without perthitic laths, lying in a groundmass mainly consisting of microperthitic feldspars of about $0{,}35$ mm in length, in broadly rectangular sections. They are often rudely sphærulitically arranged, in which case the extinction at the rotation of the slide between crossed nicols successively passes over each individual without sudden change when passing from one to another. This may depend upon the fact that the present sphærulitic body is the result of the recrystallization of another with finer feldspars. Small prismatic individuals of fibrous uralite with remains of augite occur in abundance, and magne-

tite, titanite and apatite as well. The last-mentioned is sometimes the centre of the sphærulitic groups of feldspars. Quartz is very sparingly present.

In a slide of the rock exposed at 5 meters, all the feldspar is microperthite in elongated individuals with jagged outlines, scarcely reaching a length of 1 mm. Some of them, however, are a little bigger and form the macroscopically visible phenocrysts. Sphærulitic grouping as in the above described slide occurs; other minerals occur in the same way as there, but apatite is less abundant.

The rock exposed at 12 meters chiefly consists of microperthite in somewhat elongated individuals (1 to 1,5 mm in length), sometimes Mannebach twins; other minerals as in the first slide.

12 to 20 meters. Covered.

20 to 21 meters. Very fine-grained, dark gray rock with some compact, rounded nodules of magnetite reaching a diameter of 1—5 mm. Around them and along capillary veins of magnetite the colour of the rock is brighter.

Under the microscope there also appear single small phenocrysts of plagioclase with a little potash-feldspar in microperthitic intergrowth, and some of hornblende. The feldspar in the groundmass is microperthite, in elongated, irregular individuals, reaching a length of 0,1 to 0,2 mm. Sphærulitic arrangement occurs. Tiny crystals of magnetite are very abundant, likewise titanite in grains and hornblende in short fibrous ribs. The nodules of magnetite are surrounded by a zone of groundmass, free from dark minerals, the width of which amounts to 0,7 mm. The lump of magnetite is often closely surrounded by a ring of broad feldspars, which reach a length of up to 0,7 mm and are plagioclase with small perthitic laths of potash-feldspar. The magnetite is devoid of crystallographic outlines and encloses hornblende, feldspar and completely allotriomorphic titanite. Similar light zones are also formed along the rows of magnetite crystals, which are the macroscopically visible veins.

21 to 25 meters. Covered.

25 to 29 meters. Gray and red rock in schlieric mixture. The former is very fine-grained with small feldspar phenocrysts, the latter is somewhat coarser and contains streaks and patches of hornblende. It also intrudes the gray one in the form of thin veins, the middle of which is occupied by hornblende.

The red variety has small, badly idiomorphic microperthite phenocrysts. The groundmass chiefly consists of microperthite lists with jagged outlines, reaching a length of 0,2 to 0,3 mm, and very often sphærulitically arranged. The centre of these groups is often a crystal of apatite, sometimes a feldspar phenocryst. Apatite is present in great quantity, the individuals reach about the same length as the feldspars; magnetite is present only in a few lumps of crystals, associated with some quartz. The streaks of hornblende may be regarded as aggregates of phenocrysts of this mineral. Titanite fills fissures of a width of 0,1 mm and extends around them as a fine network in the feldspars.—The dark variety is rather like the rock exposed at 20 to 21 meters, but it is much more fine-grained and abundant in dark minerals, especially in magnetite and titanite. The boundary between the two varieties is rather abrupt, but they are

surely contemporaneous. The veins which the red rock inserts into the dark one are, under the microscope, seen to be a transitory form between the two and are probably phases of the latter, developed around the aggregations of dark minerals. (See the description above of the light zones round the lines of magnetite crystals!)

29 to 35 meters. Covered.

35 to 39 meters. Fine-grained, reddish gray rock with a few small feldspar phenocrysts and patches of hornblende.

Under the microscope the rock is seen to consist mainly of microperthite in irregular, somewhat elongated individuals, scarcely 1 mm long; the phenocrysts differ from the rest only in having somewhat larger dimensions. Magnetite and hornblende are rather abundant, titanite is more sparingly present.

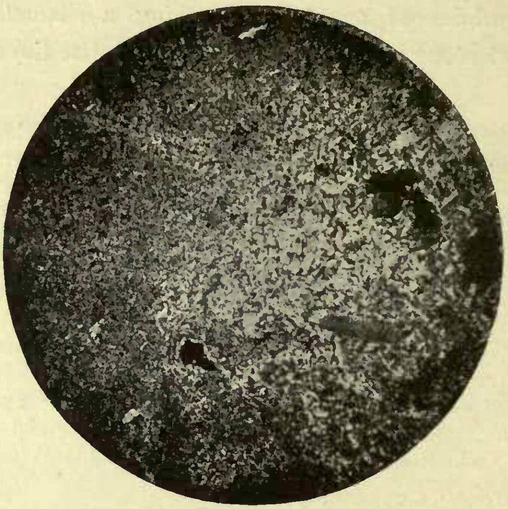

Fig. 6. Contact between the dark gray and the pink rock at 25—29 meters, profile No. II Nic. + Magn. 10 times.

In the outcrops somewhat north of the profile line it has been observed, that the rocks more to the east are true porphyries, while those more to the west on both sides of the great quartz-porphyry dike (see the map!) are fine- or medium-grained syenite.

The profile illustrates the repeated, sudden alternations between somewhat eugranitic phases, and phases of real porphyritic structure. The different varieties strike pretty much in the longitudinal direction of the mountain and have but little extent in this direction.

This sudden alternation between eugranitic and porphyritic varieties of the same mineralogical composition and often also with similarity in the structure (e. g. the sphærulitic arrangement of the feldspars) is cha-

racteristic also of the kinds of rock between the two profiles and has its analogies also in the porphyries. The direction of the strike is always nearly parallel to the longitudinal direction of the mountain. Similar variations occur in the ore-bearing syenitic rocks in northern Ural, as described by HÖGBOM [24 p. 120—121]. As will be shown in a following chapter, these rocks are in almost every respect very similar to those of the Kiruna region.

Syenite-porphyries.

Although these rocks, together with those above described and very likely also together with the porphyries on western Luossavaara and immediately north of it, are phases of the same geological unit, several different types may be distinguished among them, differing from one another by the mineralogical composition or the structure. In the following part will be described, first the principal types, their macroscopic and microscopic characters, and then some special types which occur only sparingly as schlieren in the former.

Macroscopic characters.

In the well exposed area on nothern Kiirunavaara, west and northwest of Grufingeniören, two types, a gray one, and a pink one, are predominating. The former contains rather sparingly white or pale gray feldspar phenocrysts, which as a rule are of a narrowly rectangular shape and reach a length of 1 or a few mm, more exceptionally even 10 mm. Phenocrysts of this size occur in a winding zone about 170 meters above the level of Luossajärvi, and more sparingly in other places as well. Especially when the phenocrysts are rather big there are often seen clusters of narrow rectangular individuals, penetrating one another. This characteristic feature and the generally sharp, square corners appear as a rule very distinctly on the weathered surfaces. Phenocrysts of a dark green mineral (pyroxene or amphibole) occur also; they are less common than the feldspars and do not reach their length.

The groundmass varies in coarseness, from distinctly syenitic phases to such as to the naked eye appear to be quite dense. As has been observed above, the former type has sometimes been found also among the more fine-grained porphyries. The most fine-grained phases are found in

the neighbourhood of the ore, but there is no gradual reduction of the size of grain towards it. The colour is gray of different shades, sometimes greenish, now and then brownish or purple gray, very often reddish. Sometimes the groundmass is pale gray with darker spots, 1 to 3 mm in diameter; the microscope shows these spots to be richer in magnetite than the rest of the rock.

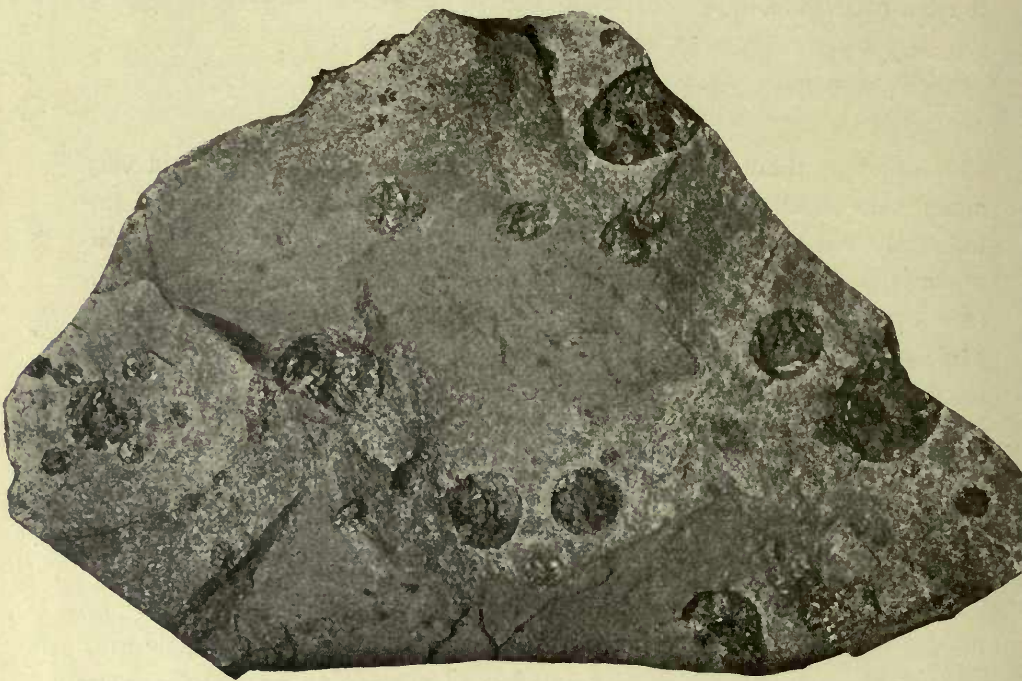

Fig. 7. Nodular syenite-porphyry, Kiirunavaara. Nat. size. Large nodules consisting mainly of biotite. The darker gray areas of the specimen are jointing planes, the lighter ones are freshly broken surfaces. The faint red rings surrounding the nodules do not appear distinctly in the figure.

Amygdule-like nodules very often occur, consisting of hornblende, titanite, magnetite, apatite and biotite, which minerals are enumerated according to their relative quantities and occur separately or several together. These nodules are often almost compact or sometimes drusy, but most often they appear as incompletely filled cavities in the rock. Their dimensions vary between a few mm and some cm. Especially the bigger ones often have a regular sphæroidal or ellipsoidal form. The rock close to such a nodule is generally of a pink colour. As a rule this zone has a width of at least some mm, but it has no relation to the size of the nodule and is more or less abruptly changed into the normal gray rock.

The nodule-forming minerals, especially the hornblende, also fill thin fissures in the rocks, not only irregular, winding ones, but also rectilinear joints. These thin veins are on both sides surrounded by a red zone, similar to the one surrounding the nodules.

The pink type is much less common than the other one. It always contains a great quantity of nodules, which often constitute one-third of the volume; the pink colour is not seen in phases devoid of nodules or of similar bodies, e. g. large aggregates of hornblende. The type evidently owes its origin to the coalescence of the pink rings around the nodules. The latter are often elongated in a certain direction, which may be con-

Fig. 8. Nodule-like body in syenite-porphyry, north-western Kiirunavaara. 1/5 of nat. size. White = syenite-porphyry; dotted = coarsely crystalline apatite; black = magnetite; striated = hornblende; at t three titanite crystals in the apatite.

sidered as a fluidal phenomenon; those contiguous generally have the same form, but the size on the other hand varies suddenly. Some loosen very easily from the rock, others are more intimately associated with it, as single mineral individuals, generally hornblende, are common to both. Besides, there occur transitions from nodules to more irregular aggregates of hornblende.

The hornblende is in this part of the mountain the most important nodule-forming mineral and its mode of occurence may well be studied here. The other components are better developed in the corresponding rocks more to the south. Each nodule is generally composed of several columnar hornblende individuals, which are arranged in different directions, with very little space left between them. A single individual is seldom found, and the nodule has then the shape of a cavity, across which the

crystal extends from one wall to the other. The hornblende is rather dark green in colour, sometimes a little fibrous, has badly developed prism faces and uneven ends without terminal faces.

The nodules sometimes have very large dimensions. One is cylindrical, 12 cm long and 3 cm in cross section, it is open, and the walls are covered with hornblende prisms. Somewhat east of the eastern end of profile No. I there are some extraordinary large bodies of this kind chiefly consisting of apatite in large crystals, hornblende and titanite; they are quite compact and sometimes enclose small rock fragments. The largest is reproduced in fig. 8. They change into veins of the same composition.

The pink nodular rock occurs now as irregular areas in the gray one, now in schlieric alternations with it. The schlieren are often only a few cm wide, their strike is usually parallel to the longitudinal axis of the mountain, the dip is steep to the east.

In the gray rocks there are often seen lumps and schlieren, usually some cm or perhaps 1 dm in diameter, which are dense and of a purely white colour but contain in their middle a black lump or streak, consisting, as shown by the microscopical examination, of magnetite, tourmaline and feldspar. The structure is somewhat similar to that of an embryonal nodule. In the tunnel somewhat above the level of the lake, this feldspar rock is sometimes predominant. It often contains big skeleton titanites.

West of Grufingeniören there is a considerable quantity of a dark gray rock with nodule-like aggregates of titanite and biotite, without any red rings.

The rocks outcropping west of Geologen and Statsrådet are in all essentials like the above described types. More to the south the outcrops are to be found almost only in the immediate vicinity of the ore, seldom more than 100 meters away from it. The rock west of the ore in Bergmästaren, Direktören, Pojken and Kapten is generally similar to the gray type. It contains single feldspar phenocrysts, sometimes reaching a length of more than 1 cm, and numerous small ones of augite and uralite. The rock is nodule-bearing, especially southwest of Kapten. The nodules are very few in number, seldom more than one on a surface of 100 square cm, but they are on the other hand uncommonly large, reaching 1 to 5 cm in diameter. They are most often quite compact, consisting of hornblende, titanite and apatite. The titanite is dark brown, some

crystal faces are well developed and lustrous. The apatite occurs as light green crystals with prismatic and pyramidal faces. A determination of the chlorine percentage of the apatite, made by N. PIHLBLAD, has given the result 0,08. The individuals of the titanite and the apatite often reach a length of 1 cm. When any space is left between these components of the nodules, it is often filled with white calcite. The nodules are most often sphæroidal or ellipsoidal. The boundaries towards the rock are as

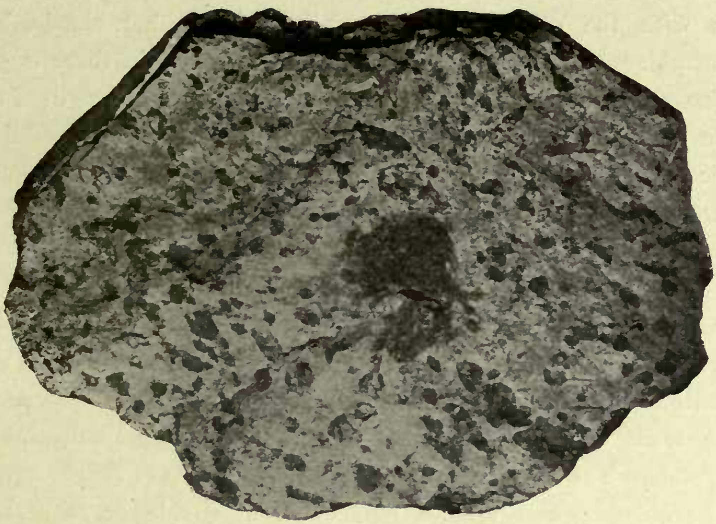

Fig. 9. Nodular syenite-porphyry, Landshöfdingen, Kiirunavaara. Nat. size. Pink feldspar rock with numerous nodules of hornblende and apatite. An apatite crystal constitutes the lower half of the large nodule in the centre of the figure.

a rule sharp and well defined. The nodule-forming minerals occur also as a coating of the jointing planes of the rock, which is somewhat reddish in the immediate vicinity of these veins and the nodules.

Mingled with these gray rocks there are also seen reddish ones of less importance, containing numerous nodules, chiefly of hornblende.

Some 50 to 75 meters west and northwest of the most northern summit of Landshöfdingen, there are some outcrops of a porphyry with numerous feldspar phenocrysts of the usual characters, embedded in a dense, dark gray groundmass.

The porphyries do not outcrop further south, but through the removal of the morainic covering for the mapping of the boundaries of the ore, they have been exposed along it to a width of some 20 meters on

Landshöfdingen and the southern part of Professorn. They are also exposed in the open cut of the last-mentioned locality.

On Landshöfdingen there occurs nodule-bearing porphyry with very fine-grained or dense groundmass. The colour is pinkish or gray of different shades, the boundaries between these different varieties are irregular and diffuse. The nodules are often very numerous (see fig. 9), rounded and well defined; they consist of hornblende, apatite and magnetite in every conceivable combination, and titanite, which is often found in combination with the other ones, especially with the hornblende, but most often occurs separately. In each apatite-bearing nodule there is generally found one or a few individuals of apatite, they reach a length of 1 cm and are pale green or wine-yellow in colour, transparent, with well-developed prismatic and often also pyramidal faces. Of the titanite only one crystal is generally found in each nodule; when no other mineral occurs the phenomenon has mostly the character of a vesicle, incompletely filled with the titanite crystal, whose faces are well developed. The habit is often the common »envelope», the faces being:

$$n = (12\bar{3}),\ P = (00\bar{1}),\ x = (1\bar{0}2),\ y = (101) \text{ and } r = (011),$$

but sometimes with n, P and x equally developed.

The walls of some open nodules are coated with small pinkish feldspar crystals. The magnetite often occurs in the form of octahedrons. Magnetite, hornblende and apatite also occur as streaks or schlieren with a width of several cm; the outlines are not very distinct. Transitions between such schlieren and nodules occur. The rock containing the schlieren is devoid of feldspar phenocrysts and dark minerals and is quite dense. It is often striped by bands free from magnetite and by other bands almost exclusively composed of this mineral in crystals. It also contains irregular apatite phenocrysts, reaching a length of some mm. Some streaks consist chiefly of muscovite in such very tiny flakes as to be called sericite, and bunches of black tourmaline.

The wall rock of Professorn is chiefly similar to that of Landshöfdingen. The hornblende in the nodules is often altered to white asbestos. The nodules of the rock next to the ore are very few, but big, reaching a diameter of 2 to 5 cm. Titanite, apatite and magnetite are developed in them as good crystals with the above described forms. Along the planes of weakness in the rock there also occur drusy aggregates of pale green apatite in crystals reaching a length of up to 6 cm and a cross section of 2 cm; the forms are the usual ones; parting parallel

to the pinacoid is rather perfect. Between the apatites there are scattered individuals of hornblende, titanite and magnetite.

The small areas exposed on Jägmästaren are a reddish porphyry with hornblende nodules.

The isolated outcrop about 340 meters west of Kapten is a gray porphyry without nodules; the groundmass is rather coarse-grained[1].

Fig. 10. Feldspar phenocryst in syenite-porphyry, northwestern Kiirun avaara. Nic. +. Magn. 35 times. The feldspar is finely cross-twinned albite, with spots of orthoclase (dark) in microperthitic intergrowth.

Microscopic characters.

Feldspar phenocrysts. Their quantity varies a good deal, in some cases they constitute nearly one-third of the whole rock, but sometimes there are only 1 or 2 in a slide of ordinary size. Their size also varies, being, as has already been stated, somewhat more than 1 cm at most, the average size may be 1 or a few mm. A minimum figure cannot be given, as they pass into the feldspars forming the groundmass, but if these are very small, the phenocrysts are seldom smaller than 0,5 mm. They are microperthitic, but the potash component is generally very subordinate and is sometimes not to be found at all.

[1] This outcrop and that of the quartz-porphyry dike described p. 159 are located at the bottom of a temporary lakelet.

The stripes are more irregular than in the similar feldspars of the syenite, and are often confined to the peripheric parts of the individual. The plagioclase is generally polysynthetically twinned according to the albite law; the breadth of the lamellæ is varying, they are, as in the syenite, generally thinner towards the outlines of the individual than in the centre. Lamellæ according to the pericline law often occur, they are often thin and mostly found only at the periphery of the crystal. This thin lamination and crosstwinning is quite like the one described on p. 4 and like that it may be considered as an indication of a soda-microcline character of the plagioclase. The albite lamellæ are sometimes irregular and short, the plagioclase is then generally limpid and has the appearance shown in fig. 20 (p. 65). As shown especially by analysis No. XII, this plagioclase must be nearly pure albite. There also occurs twinning according to the Carlsbad law and of the Roc-tourné type; the simple Mannebach twins of microperthite, which are so common in the syenite, are also found.

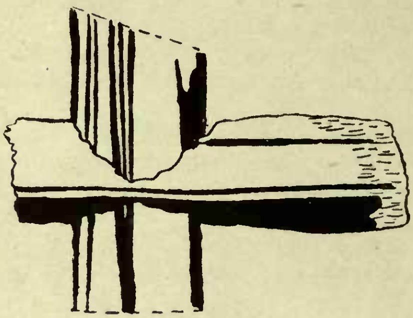

Fig. 11. Plagioclase phenocryst in syenite-porphyry, showing penetration. Magn. about 30 times.

The habit is generally thickly tabular parallel to the pinacoid (010); the Mannebach twins are often tabular to (001). Penetration between two tabular individuals as shown in fig. 11 is often seen. The angle varies within wide limits: 40° and 90°. HEINECK [19] has described quite similar phenocrysts in diabases, and because of a frequently occurring angle of 60° he considers the phenomenon as a penetration twinning parallel to the face (130). In a porphyrite boulder from the valley of the Skellefte river, Västerbotten, Sweden, whose plagioclase phenocrysts are well exposed on account of the intense weathering of the groundmass, they appear very plainly to be tabular parallel to (010), many phenocrysts being composed of 2 or more such tabular individuals penetrating one another in various directions, but with the pinacoid faces (010) always at right angles to each other. It is probably just the same in the case of our syenite-porphyries.

As the rocks of this group vary between fine-grained syenite and types, the groundmass-feldspars of which reach only some hundredth of a millimeter in length, it is only natural that the idiomorphism of the phenocrysts is also varying. As stated above, they differ in the coarsest phases from the other feldspars almost only by their dimensions; their outlines are almost as irregular as those of these feldspars themselves. On the other hand, if we look at an opposite type, for instance the rock in some outcrops just west of south Grufingeniören, we find that the outlines of the phenocrysts appear to be quite rectilinear, without any curves or irregularities even when magnified 100 times; in dimensions these feldspars surpass those of the groundmass about 100 times. The increasing

idiomorphism appears in the connecting parts as follows: the sections first assume a rudely rectangular shape, the angles then grow acute while the sides may still be jagged. Sections at right angles to (010) often have better idiomorphic outlines than those more parallel to this pinacoid. »Corrosion bays» are very rare.

Small crystals of magnetite are often enclosed in the phenocrysts, but the mineral is more seldom found in them than in the groundmass, it is sometimes very abundant in the latter but is not seen at all in the phenocrysts.

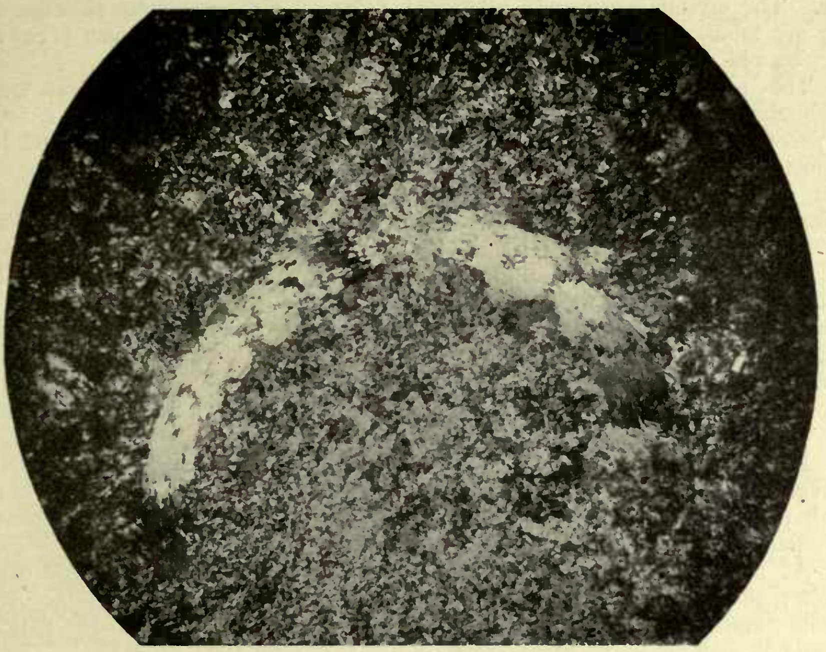

Fig. 12. Semi-circular uralite sheaf in syenite-porphyry, northern Kiirunavaara. Nic. +. Magn. 14 times. The ends of the sheaf and a little part of the middle are dark, the rest is white.

Apatite is not often found as inclusion, nor is hornblende, which occurs in the shape of small, fibrous columns. It is perhaps of secondary origin. The biotite, with the same optical character as that of the syenite, occurs as small plates in the phenocrysts, sometimes in great abundance. It sometimes fills fissures in the phenocrysts, as is the case also at Mertainen [6] and is very probably secondary, it is perhaps pneumatolytically formed. (The titanite is described p. 30). Calcite in small irregular grains is rather abundant, and epidote is often seen, especially in the centre of the phenocrysts. The feldspar even alters to muscovite (paragonite?) just as in the syenite. But on the whole these phenocrysts are not much altered.

Augite and uralite phenocrysts. Pyroxene is more seldom seen in the porphyries than in the syenite, but this dissimilarity is very probably only secondary, caused by an unequal degree of uralitisation in these two kinds of rock. All unaltered pyroxene individuals have the same optical properties as

those of the syenite and are consequently diopsidic augite. The phenocrysts are not as numerous as those of feldspar and smaller than the latter, generally not more than 1 mm long. West of Bergmästaren there are, however, phenocrysts with a length of 1 cm and more. The idiomorphism is rather good, but terminal faces are as a rule not developed. Northwest of the north summit of Landshöfdingen there is a small area of a peculiar rock variety, without any feldspar phenocrysts but with phenocrysts of augite, reaching a length of 0,3 to 1 mm and lying in a fine-grained feldspar groundmass. The augite constitutes about the half of the rock. The crystal habit of it can be well determined here. The crystals are mostly idiomorphic, but at times somewhat skeleton-like, they are tabular and bounded by the pinacoid (100), with the prism (110) and the pinacoid (010) rather subordinate. Twinning is common.

The process of uralitisation passes just as in the syenite, and the uralite which develops is the same common hornblende as there. As a rule it seems to preserve the outlines of the augite, only at the ends of the crystal it is irregular and fibrous. Even the twinning of the augite is preserved. The relations of the augite and uralite phenocrysts to those of feldspar are not very distinct, but the scanty finds of uralite enclosed in a feldspar seem to indicate that the former are older, at least sometimes.

Many signs suggest that the hornblende also replaces the feldspar and to a much larger extent than has been observed in the syenite, where, as has already been stated, such phenomena also occur in connection with the uralitisation. We allude especially to the occurence of very long, regularly curved, fibrous hornblende individuals, which often do not form one continuous crystal but only a row of small sheaves. One individual of this kind is semicircular (188°) with a radius of 3 mm. See fig. 12.

Hornblende of distinctly primary origin is never seen except in the nodules. Though this mineral, when forming the latter, optically corresponds to the uralite in all respects, it never shows the crystal forms of the augite nor any remnants of it but gives a very strong impression of being primary.

As inclusions ocur the same moinerals as in the augite and uralite of the syenite; the alteration is just as incltnsiderable and its products are the same: titanite, epidote, chlorite. Uralite aeering to chlorite generally grows dark on account of the development of magnctite in tiny grains.

The groundmass. The groundmass consists chiefly of feldspar, further of dark silicates (augite, uralite, and a small quantity of biotite), magnetite, titanite and apatite in varying quantities, and, but only seldom, zircon. Other minerals seen in it are probably all products of the alteration of those just enumerated. The dark minerals sometimes constitute about 40 per cent of the volume of the groundmass, but are sometimes not seen at all. *In the light, usually pinkish, nodule-bearing rocks, and in the red zones surrounding the scattered nodules and the hornblende veins in the gray varieties, there are no dark minerals at all, neither as phenocrysts nor in the groundmass. This is the only difference between the two varieties.* (In one slide, the groundmass of which is quite free from dark minerals, thetre are a few magnetite crystals enclosed in the feldspar phenocrysts). The relalions between the magnetite and the dark silicates vary, they are often equaly abundant. Magnetite occurs nearly always,[1] and is sometimes, as will be described later on, the only dark constituent, even in rocks with a quite decidedly femic character.

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[1] Here is naturally the question only of the varieties, in which dark minerals cocur at all.

The feldspars of the same slide are generally of the same size, only it happens very seldom that adjacent individuals have very different dimensions or that the size of grain varies in spots. In the latter case the coarse areas are rather similar to nodules and are often doubtless to be considered as »embryonal» nodules. The individuals most often reach a length of 0,1 to 0,2 mm, but sometimes their size is but some hundredths of a millimeter. The microscopic examination confirms the observations mentioned above concerning the changes in the size of grain of these rocks. In the rocks of the northern part of Kiirunavaara the feldspars are generally isometric or somewhat elongated. Here and there within this area and especially more to the south they are shaped more like lists, the

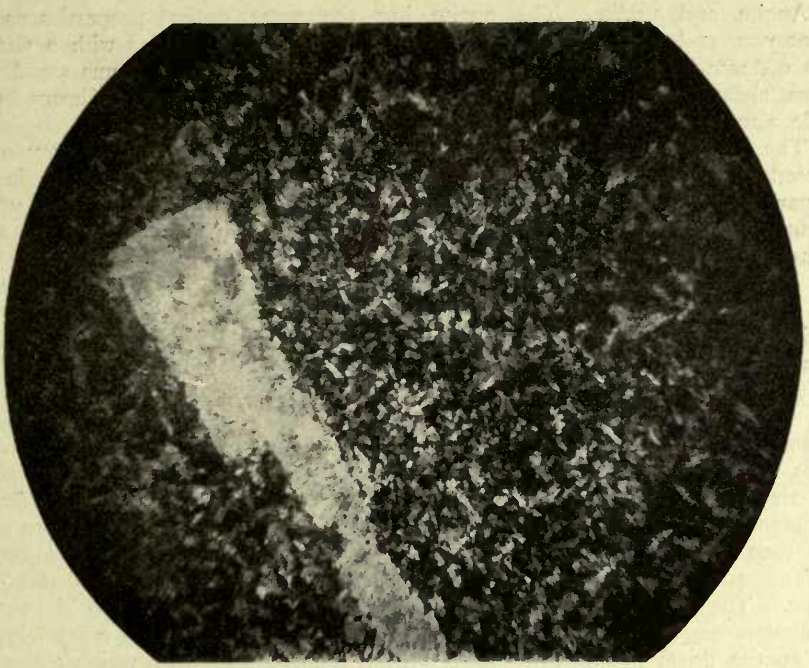

Fig. 13. Syenite-porphyry, Landshöfdingen, Kiirunavaara. Nic. + Magn. 35 times. Badly idiomorphic microperthite phenocryst, and typical feldspar groundmass.

length being 3 or 4 times the width, and elongated parallel to the axis a. They are then rather irregularly arranged and very seldom show any signs of trachytoidal arrangement. In the rather coarse varieties the structure is similar to that of the syenite, but in the fine-grained ones the outlines of the feldspars are sinuous and the different individuals grip into one another like teeth. The occurrence of a rudely radial arrangement has already been described (p. 17, 18); it is on the whole rare. Still more unusual is a real sphærulitic structure (see below p. 31).

The feldspar is generally microperthite, but the intergrowth is coarser and more irregular than in the phenocrysts. Microperthitic characters are often not very easily distinguished, especially in the rather fine-grained varieties. The plagioclase component is often twinned according to the albite law, sometimes striped, but rather seldom crosstwinned. The lamination is sometimes extremely

thin and the feldspar then resembles the presumed soda-microcline of the syenite; in numerous cases, when no twinning can be seen, the lamellæ are probably too thin to be distinguished by the magnifications (400 times), that have been used. As the phenocrysts contain less potash-feldspar than the microperthite of the syenite, one might expect an increase of potash in the groundmass. The analyses also show that the potash percentage of the whole rock is about the same as that of the syenite. But it is very difficult to find out how much of the feldspar is microperthite and if individuals of free potash-feldspar may not occur. The small size of grain and the high percentage of other minerals, especially that of fibrous hornblende, make such determinations very difficult. These feldspars seem to be less altered than the phenocrysts.

Augite and uralite. The augite has the same optical properties as the phenocrysts and occurs in the shape of almost isometric grains with a size of about $0{,}1$ mm. It is as a rule transformed into uralite, which forms small and fibrous sheaves with a length of $0{,}10$ to $0{,}15$ mm. This form of fibrous hornblende also seems to have replaced the feldspar to some extent.

The magnetite belongs to the first crystallizing minerals and is very often enclosed in the others, but only seldom, as has already been mentioned, in the feldspar phenocrysts. It occurs in single crystals or in angular lumps, which evidently are aggregates of crystals; the latter often reach a size of more than $0{,}1$ mm, the former are generally much smaller. The magnetite is very irregularly distributed throughout the rock, it is very abundant in some parts, in other parts it is scarcely seen at all. This is the case of the rock with gray spots, described p. 20; when the change is on a large scale there appears a schlieric alternation between normal porphyry and some varieties very rich in magnetite, which we are going to speak of further on. Very peculiar is the occurrence of rows of magnetite crystals, bordered on both sides by a zone free from this mineral; this phenomenon (already described on p. 18) is rather common. It is not a filling of a fissure. Some of the big magnetite lumps are surrounded by a rim of titanite, in the same way as is sometimes seen in the syenite. If the magnetite of the rock were very titaniferous, such rims ought to be seen more often than is now the case, it is therefore probable that also ilmenite is present.

The apatite of the porphyries is generally rather similar to that of the syenite. The quantity is just as varying and the same is the case with the dimensions and the form. A rather peculiar detail is worth mentioning: a long apatite prism includes two small angular feldspar fragments, which extinguish at the same time as the apatite. Stutzer has also observed a similar case, [62, p. 572] his slide as well as the writer's is from the wall rock of Landshöfdingen. But the phenomenon must be rare, as the writer has not found it in any other slide. Crystals of apatite included in the feldspar phenocrysts are more often seen.

The titanite occurring in the porphyries has the same optical properties as that of the syenite. Its quantity varies a good deal, and as the titanite in the nodules is also included in the analyses, the quantity in the remaining rock cannot be estimated by them. But the titanite is probably as common here as in the syenite. It sometimes shows a trace of idiomorphism, but as a rule it is quite similar to the second type, described p. 8. In most feldspar phenocrysts it is seen in the form of rounded or branching lumps, which sometimes occupy half the phenocryst. These titanite individuals sometimes project into the groundmass. The mineral there mostly occurs in the shape of small rounded lumps or as a fine network, in the latter case often with a compact lump in the centre. Such individuals may reach a diameter of more than 1 mm. Their

relations to the augite, the uralite, the magnetite and the apatite are described above. Thin veins of titanite are very common. The titanite sometimes alters to a yellowish brown substance, probably a mixture of iron hydrate and calcite, enclosing rutile.

Orthite. In some slides from Landshöfdingen there are seen near the nodules some small irregular grains, which probably belong to this mineral. The pleochroism is strong in gold green and dark brown colours. Twinning is common.

Zircon is very seldom seen, it is like that of the syenite; quartz of primary origin is almost totally absent.

The biotite has the same optical properties as that of the syenite. In most slides it occurs only very sparingly, but in others it is the predominating dark silicate. It generally appears in the shape of very tiny plates, scattered through the feldspar phenocrysts and the groundmass, even in the latter case often included in the feldspars. These biotite plates make the impression of being primary constituents of the rock. But the mineral also fills cracks and fissures in the feldspar phenocrysts and occurs as tiny veinlets in the groundmass, it is then often associated with calcite, sometimes also with quartz. It is very probable that this biotite is secondary as well as that occurring along the cleavage cracks in the uralite. Calcite occurs rather often as small irregular grains, in the feldspar phenocrysts as well as in the groundmass, and as stated above associated with biotite and quartz in thin veins as well. The occurrence of epidote, muscovite and chlorite as products of alteration is already described.

Pseudomorphoses. In a slide of the wall rock on southern Landshöfdingen there occur a few rounded patches, some mm in diameter, which consist mostly of small biotite plates and some quartz grains. In this matrix there are numerous prismatic individuals of a mineral which probably is rutile. It is of the same yellowish brown colour as weathered titanite, and this muddy hue renders the determination of its optical properties very difficult. It has a distinct cleavage parallel to the longitudinal axis of the prisms, and parallel extinction. The prisms are often very elongated, acicular, and often have crosswise arranged small needles. These elongated individuals are arranged in two systems, forming an angle of about 49° with one another; they are often grown together at this angle but never at an angle of about 82° as might also be expected. These patches seem to be pseudomorphoses after a titaniferous mineral, but which this mineral is cannot be determined.

Sphærulitic rock. On the northern slope of the mountain there is a dense, dark variety, with small feldspar phenocrysts. The microscope shows the groundmass to be very rich in magnetite and hornblende, both as very small grains, the former reaching a size of $0,_{01}$ mm, the latter somewhat more. In some parts of the slide, these dark minerals seem to be equally distributed in the feldspar mass, but in parts they are arranged in long rows, often reaching a length of $0,_3$ to $0,_4$ mm, while the width is $0,_{01}$ to $0,_{02}$ mm; in these both minerals occur together. These rows form sparse bunches or are lying parallel to one another, sometimes covering areas of $0,_5$ mm in diameter, or are arranged as the rays of a fan; different systems sometimes cross one another. The groups of unarranged grains are perhaps such bunches in cross section. The feldspars are sometimes distinctly list-shaped, often very thin, there occurs for instance an individual with a length of $0,_6$ mm, but only about $0,_{02}$ mm wide. There is very often seen a beautiful sphærulitic arrangement of these rays, often as a continuation of small phenocrysts. In the greatest part of the slide, the mutual outlines of the different feldspars cannot be distinguished, the

extinction shadows show, that the mass is somewhat irregularly sphærulitic. It is rather strange that no relation between this arrangement and that of he dark minerals can be observed.

The rock has consequently a more pronounced volcanic character than the other varieties of the syenite-porphyries, but in some other parts of these there are also seen similar features.

The nodules. Mineral constituents are hornblende, magnetite, titanite, apatite, feldspar, enumerated according to their relative quantities, rather seldom biotite and quartz, and in one place muscovite and tourmaline. All these minerals have about the same optical properties as they have in the surrounding rock. The titanite shows the usual cleavage, connected with twinning, and now and then a perfect system, dividing the angles of the other one into halves, and single cracks at right angles of this marked system. The best cleavage is almost parallel to the plane of the optical axes. The apatite shows an irregular parting parallel to the pinacoid, it is sometimes uniaxial, but sometimes strongly biaxial. It often includes small red flakes of hematite (»Eisenglimmer»). The feldspar is microperthite, most like that of the fine-grained syenite. The plagioclase component is generally polysynthetically twinned, more seldom cross-twinned; simple Mannebach twins also occur. Individuals rather like soda-microcline are also seen. The tourmaline is pleochroic with the following colours: $O =$ olive brown or blue; $E =$ pinkish; absorption $O > E$.

The structure. The outlines of the nodules towards the surrounding groundmass are generally rather distinct, and the groundmass preserves its usual structure close to the nodule. But »embryonal» nodules sometimes occur, consisting mostly of feldspar or hornblende and appearing only as parts structurally differing from the groundmass. When feldspar occurs, it first forms a ring round the nodule, the outline of this ring towards the groundmass is generally a regular curved line, more seldom each individual projects in it so as to make the outlines of the nodule scalloped. The feldspars generally reach a size of 0,2 to 0,8 mm in diameter and are nearly isometric. The ring is often multiplex, and the nodule sometimes consists only of feldspars, the structure then being very similar to that of the syenite. They are sometimes radially arranged and grow thinner towards the centre of the nodule, which may consist of a rather big, isometric individual. The hornblende prisms project in the groundmass; the titanite individuals do the same. In one case the titanite is idiomorphic towards the groundmass.

In compact nodules no constituent is idiomorphic, the structure is most properly characterized as panidiomorphic; the border between the hornblende on one hand and the magnetite and the titanite on the other hand generally follow the prismatic cleavage cracks of the hornblende, but it also occurs that magnetite crystals are included in the hornblende, or that this mineral and the titanite are intergrown in a granophyric manner. The latter case may perhaps, as similar, before described phenomena, be accounted for by the titanite's being of secondary origin. The relations between the feldspar and the magnetite or the hornblende are principally analogous, but the boundary between the feldspar and the titanite are generally more irregular. The apatite very often occurs immediately outside the nodule, within the light zone. Quartz occurs in some slides from Landshöfdingen as mesostasis between the other nodule-forming minerals, also in the groundmass, especially close by the nodules, in optically homogeneous areas with a diameter of 0,2 to 0,4 mm and containing numerous inclusions of small feldspars. These patches of quartz seem to be secondary; in their mode of occurrence they remind one of new-formed topaz.

In a slide of the wall rock north of Vaktmästaren, between Kiirunavaara and lake Luossajärvi, there are numerous nodules consisting almost entirely of quartz in irregular grains, or of quartz and microperthite. Biotite occurs as a rule only in very small flakes, especially associated with quartz and enclosed in it. The tourmaline-bearing streaks in the wall rock on Landshöfdingen consist of muscovite, tourmaline and hematite. The tourmaline is idiomorphic towards the muscovite, but includes hematite. The crystals have the form of short prisms and reach a length of a few mm; very often they show zonal structure: a blue colour in the centre, and olive brown around. The mineral accumulates along the borders of the streaks. Similar nodules, very elongated and almost vein-like, consisting of feldspar, hornblende and titanite, are also seen, but they are rather rare.

Chemical characters.

	III	III a	IV	IV a	IV b	V	V a	VI	VI a
SiO_2	60.78	1006	59.71	989	66.42	60.97	1009	61.12	1012
Al_2O_3	14.95	147	16.18	158	10.64	15.39	151	17.06	167
Fe_2O_3	4.04	25	4.89	31		3.29	21	3.20	20
FeO	2.27	32	2.64	37	6.27	1.19	17	2.96	41
MnO	0.07	1	0.09	1	0.01	0.36	5	0.23	3
MgO	2.39	60	1.54	38	2.56	3.39	85	1.17	29
CaO	3.22	58	3.77	67	4.52	5.04	90	2.91	52
Na_2O	5.81	94	5.93	95	6.41	5.65	91	7.25	117
K_2O	3.53	38	3.69	39	2.63	2.88	31	2.04	22
H_2O +	0.53	29	0.22	12		0.60	33	0.74	41
TiO_2	2.14	27	0.66	8	0.55	1.65	21	1.35	17
P_2O_5	0.01		0.44	3	1)	0.11	1	0.02	
S			trace			n. d.		n. d.	
Sum	99.74		99.76			100.52		100.05	
H_2O −	0.18		0.07			n. d.		n. d.	

No. III. Pink porphyry with numerous nodules, which consist chiefly of hornblende. Northwestern Kiirunavaara (G. NYBLOM analyst).

No. III a. The molecular proportions of No. III, multipl. by 1000.

No. IV. Gray porphyry without nodules. Northwestern Kiirunavaara, about 35 meters from No. III (G. NYBLOM analyst).

No. IV a. See No. III a.

No. IV b. The molecular proportions of No. IV, calculated on a sum of 100, free from H_2O, all Fe as FeO.

No. V. Gray porphyry. West of Kapten (H. SANTESSON analyst) [42].

No. V a. See No. III a.

No. VI. Grayish red porphyry. Northern Kiirunavaara (H. SANTESSON analyst) [42].

No. VI a. See No. III a.

American system.

No. IV.				Norm.		
Quartz	SiO_2		3.99	Q	3.99	Sal 82.52
Orthoclase	$K_2O . Al_2O_3 . 6 SiO_2$		21.80			
Albite	$Na_2O . Al_2O_3 . 6 SiO_2$		50.05	F	78.53	
Anorthite	$CaO . Al_2O_3 . 2 SiO_2$		6.68			
Diopside	$CaO . SiO_2$	3.84	7.16	P	7.66	Fem 16.93
	$MgO . SiO_2$	3.32				
Hypersthene	$MgO . SiO_2$		0.50			
Magnetite	$FeO . Fe_2O_3$		6.96			
Hematite	Fe_2O_3		0.16	M	8.34	
Ilmenite	$FeO . TiO_2$		1.22			
Apatite	$3 CaO . P_2O_5$		0.93	A	0.93	

Sum 99.54 + H_2O = 99.67

Class 2 Dosalane, Subclass 1 Dosalone, Order 5 Germanare, Rang 2 Monzonase, Subrang 4 *Akerose.*

Osann's system.

	s	A	C	F	a	c	f	n	k
No. IV	66.97	9.04	1.60	11.76	8	1.5	10.5	7.1	0.97

Those among Osann's types which most resemble No. IV are the Hedrum syenite and the Yogo Peak monzonite, the formulæ of which are respectively s58 a9.5 c1 f9.5 and s67 a7 c1.5 f11.5.

Varieties especially rich in magnetite.

These rocks occur here and there as quantitatively subordinate schlieren in those above described, their outlines towards them are often rather distinct. Mineralogically they are composed chiefly of feldspar and magnetite and contain consequently very little CaO and still less MgO. Only the most important types will be described here.

Some 10 meters east of the eastern end of profile No. I there occurs a fine-grained dark gray rock with small rectangular feldspar phenocrysts. The groundmass consists principally of microperthite in list-shaped individuals, reaching a size of 0,2 to 0,3 mm and sphærulitically arranged, and of magnetite, which appears to constitute about 20 per cent of the whole groundmass. It occurs in the shape of small crystals or aggregates of crystals.

About 350 meters west of the summit of Geologen, there are some schlieren, only a few dm wide, of dark gray rock with numerous nodules, which sometimes constitute nearly half the rock and consist of magnetite, apatite, hornblende and titanite. They are surrounded by a sharply defined purely white ring.

Fig. 14. Nodular rock, rich in magnetite, west of Geologen, Kiirunavaara. Ord. light. Magn. 10 times. The black masses are magnetite, the white zone surrounding them consists of two rings, the inner one of large microperthite crystals, the outer one of feldspar groundmass. The rest of the rock is made up of a normal groundmass of feldspar and magnetite. Within the nodules there is further seen much apatite in large individuals (of a light gray colour), some hornblende (known by its straight cleavage cracks) and some titanite. (In the middle and upper right of the figure there are holes within two of the nodules, these white areas are known by a faint dust rand surrounding them).

The microscopic examination shows the following. A few rectangular microperthite phenocrysts, reaching a length of some mm at most, lie in a groundmass consisting of microperthitic feldspar and magnetite, with small quantities of titanite and apatite. The feldspars are list-shaped, and reach a length of about 0,15 mm. The magnetite constitutes at least 20 per cent of the volume and appears in crystals of a very varying size, often accumulated in lumps, and lying within or between the feldspars. The nodules are surrounded by a zone with no magnetite at all, while the feldspars generally have the usual appearance, being somewhat smaller now and then. This zone is 0,2 to 0,6 mm wide; together with the frequently occurring ring of larger feldspars round the nodule it forms the macroscopically conspicuous white ring. The nodule inside this garland consists of the minerals enumerated above, especially

magnetite. One nodule reaches a length of some cm and consists chiefly of fine-grained apatite and feldspar, with a small amount of hornblende and zircon, in the centre there is a feldspar nodule of the usual appearance. Its most striking feature is the shape of the apatite individuals: they are sinuous and jagged grains with a diameter of 0,2 to 0,3 mm, sometimes forming continuous, optically homogeneous areas of much larger dimensions.

Only some ten meters west of the ore of Statsrådet there occurs a dark gray, nodular rock, which, judging from the occurence of numerous

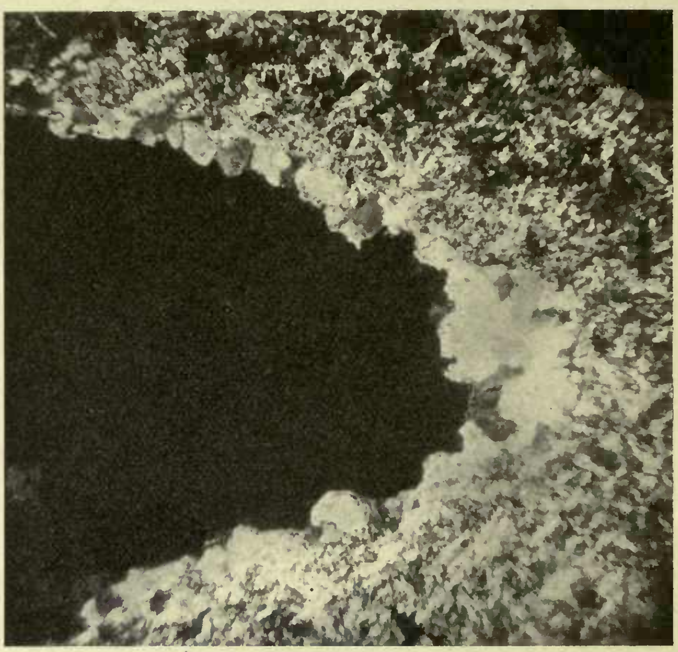

Fig. 15. The right half of the largest nodule in fig. 14. Nic. +. Magn. 35 times. The black lump of magnetite is surrounded by a simple frame of microperthite, outside it follows normal feldspar groundmass and then feldspar-magnetite groundmass.

boulders in the moraine, has a considerable distribution in a zone somewhat west of the ore, though generally covered with moraine. The rock has feldspar phenocrysts reaching a size of some mm. The nodules are sphæroidal or ellipsoidal, reaching a diameter of 1 to 30 mm, most of them are compact but many are drusy. Most closely to the border there is pinkish feldspar, sometimes in individuals more than 1 mm long, now and then projecting in the groundmass. Other constituents are black biotite, magnetite, titanite and hornblende. Small hornblende prisms adhere to the feldspars.

The microscope schows the phenocrysts to be microperthite of the usual type, enclosing lumps of titanite, small flakes of biotite and apatite prisms. The groundmass consists of microperthite in list-shaped individuals, 0,1 to 0,2 mm in length, of magnetite, and often considerable quantities of biotite in the shape of small plates with a size of about 0,2 mm, some hornblende, titanite and apatite. The magnetite constitutes 20 to 25 per cent of the volume of the groundmass and is always idiomorphic but generally squeezed together between the feldspars or at their borders, very seldom it is enclosed within them. In ordinary light, especially when under a weak magnifying power, the groundmass therefore appears black with rectangular white areas.[1] The biotite occurs especially as a frame around the feldspar phenocrysts, in part lying within them, but is not seen filling fissures.

The nodules are never surrounded by a zone free from magnetite. Their feldspar it microperthite like that of the syenite, but the potash component is sometimes predominating. There are sometimes present enclosed magnetite crystals of the same shape and in about the same quantity as in the groundmass, but only in the feldspars immediately adjacent to the same. Apatite is frequently seen in the nodules but is almost as often found just out of them. The other minerals offer nothing of special interest.

About 100 meters west-southwest of Kapten there occurs a reddish gray rock with numerous nodules of magnetite and hornblende. The nodules are mostly ellipsoidal and generally reach a length of 2 to 10 mm. Besides, rather big lumps and schlieren occur, now and then reaching a size of 1 dm in diameter, consisting of gray, fine-grained magnetite, evidently mixed with some other mineral. The outlines of these ore lumps are sinuous towards the rock and enclosed fragments of it in a way showing, that they have originated through the coalescence of numerous nodules of normal dimensions.

Under the microscope the normal rock shows nothing very remarkable. The groundmass is fine-grained and contains scattered crystals of magnetite, which, however, are not seen in the immediate neighbourhood of the nodules. The latter often have a wreath of feldspar; but magnetite and hornblende are the main constituents, quartz and biotite are present in very small quantities. The nodules are often so near one another that they are only separated by a single row of groundmass feldspar or partly join. Many nodules, and among them the big lumps of ore, are composed of microperthite and magnetite in almost equal volumes. The feldspar individuals are broadly rectangular and generally reach a length of 0,15 to 0,30 mm. The magnetite forms a sort af mesostasis to them, and thus they are, alone or in groups of a few individuals, always enclosed in magnetite. But the latter has, nevertheless, angular outlines and evidently consists of aggregates of crystals. This peculiar structure is thus similar to that of the groundmass of feldspar and magnetite, described above; it is perhaps not quite as pronounced as that from the ore field of Nokutusvaara, see fig. 59. Numerous small nodules of this sort are »embryonal», with indistinct borders towards the groundmass.

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[1] A very similar structure is seen in fig. 19 (p. 64),

Varieties especially rich in apatitie.

Distribution and macroscopic characters.

Though the apatite very often makes up some per cent of the rock, it is present in a greater quantity only within a very limited area. This area is located some ten meters west of the ore, on south Bergmästaren. The porphyries there are mostly moraine-covered and exposed only in a little prospecting trench with an east-westerly direction and about 8 meters in length.

Farthest east there is a grayish green porphyry of the usual type, intersected by veins consisting of apatite, magnetite and hornblende. These veins are rather rectilinear in their course and reach a width of about 6 cm at the utmost. The apatite occurs in crystals with a length of about 1 cm and of a pink or green colour, the magnetite is dense, lustrous, and occurs especially along the borders. The contacts with the wall rock are always distinct and well defined. Only a few meters from the eastern end of the trench the rock begins to contain small nodules and very suddenly grades into a series of peculiar and very heterogeneous rocks. The trench has partly collapsed, and the variations can therefore be examined in part only. A pinkish variety is widely distributed; it contains compact nodules composed mostly of hornblende but also to some extent of magnetite, they are sometimes almost sphæroidal, sometimes elongated and then often fluidally arranged, in whirl-like groups. In this rock there are schlieren, generally scarcely 1 dm wide, blackish gray in colour, with nodules of magnetite or hornblende. Especially around the former there is a distinct white ring, it is less distinct around those composed exclusively of hornblende. The schlieren are sometimes almost black, consisting mainly of magnetite. There are also schlieren and irregular lumps, often several dm in diameter, consisting of apatite, the minor constituents being magnetite and hornblende. There also occur transitory forms between phases composed exclusively of these minerals, and the ordinary nodular rock. The apatite crystals often reach a length of 1 cm and are of a pinkish or pale green colour; the magnetite usually occurs in the shape of bluish black coarsely crystalline lumps, the hornblende in dark green prisms of about the same size at the apatites.

In the western half of the trench there is also an outcrop of a grayish white rock with hornblende phenocrysts, it is connected by transitions with those mentioned above. It contains numerous hornblende nodules, reaching a length of only a few mm, and elongated, causing a flow structure in the usual direction. Apatite grains constitute nearly half the volume. They reach a diameter of 1 to 10 mm, and generally have rounded or irregular outlines. Finely distributed magnetite occurs in spots, and usually in quite the same way in the feldspar rock and in the apatites, sometimes

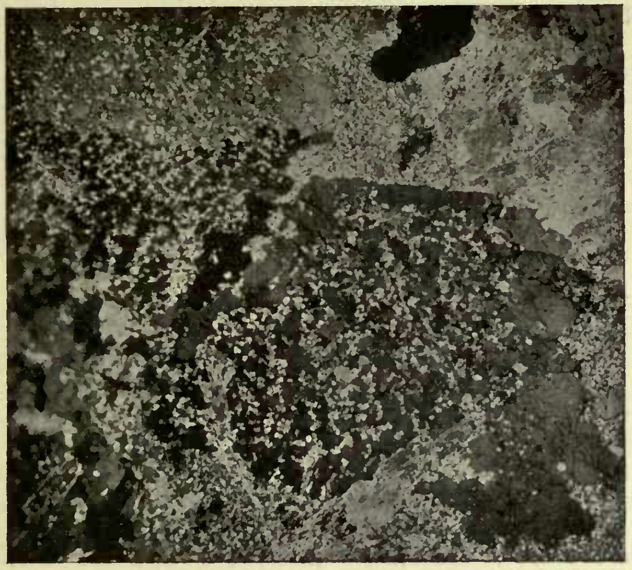

Fig. 16. Rock rich in apatite, Bergmästaren, Kiirunavaara. Nic. +. Magn. 14 times. The dark gray areas are apatite, with numerous small inclusions of groundmass. Upper left hand corner is occupied by an apatite individual (light gray) forming the continuation of the nearest dark one.

it occurs in large areas almost pure. A characteristic feature of this rock is the occurrence of numerous hornblende phenocrysts with a length of up to some cm, they are arranged in different directions and occur in about the same quantities in the feldspar rock, the apatite and the magnetite. When they are present in the concentrations of magnetite, the combination resembles the pyroxene- or hornblende-bearing ore, described p. 102. One individual is often common to for instance both an apatite grain and the surrounding feldspar mass; it often happens, however that the prisms enclosed in the apatite are smaller than those beyond it.

Microscopic characters.

The grayish green porphyry at the eastern end of the trench offers nothing very remarkable. The pinkish, nodular rock has feldspar phenocrysts of the common type, with skeletons of titanite and small biotite plates, and small quantities of epidote and muscovite. Besides there occur hornblende phenocrysts and rather irregular phenocrysts of apatite, partly in great abundance. The groundmass consists principally of feldspar, the individuals scarcely reaching 0,1 mm in length. Moreover there are some magnetite and apatite, the former sometimes being included in the latter. The nodules are »embryonal» and consist chiefly of feldspar, hornblende and apatite.

The schlieren, which are rich in magnetite, show even under the microscope an obvious trasition to the precedent type. Magnetite is never present in the feldspar phenocrysts but often constitutes half the volume of the groundmass. It is often concentrated in angular lumps. The feldspar individuals are sometimes more elongated than in the above described type, and often trachytoidally arranged. In this rock too there are some phenocrysts of apatite and lumps of titanite. The nodules are surrounded by a zone free from magnetite (the macroscopically visible white ring), they are generally rounded, with well defined outlines, and consist mostly of magnetite and feldspar, the latter sometimes being found at the periphery, sometimes within the magnetite. Hornblende occurs too, probably also apatite, though the writer has not seen it in his slides.

The white rock with hornblende phenocrysts and much apatite has scarcely any feldspar phenocrysts. The groundmass consists principally of feldspar and resembles that of the pinkish nodular rock already described above. Neither hornblende nor apatite occurs in more than one generation, they are therefore scarcely to be called phenocrysts. The hornblende crystals generally reach a length of 1 to 10 mm and have a rather good idiomorphism in the prism zone. Very often they contain small remnants of augite, and are consequently uralite. The apatite occurs in a very unusual way, in individuals reaching up to 1 cm in diameter. It includes numerous small areas of groundmass-feldspar; these inclusions have irregular outlines and generally reach a size of 0,1 to 0,2 mm. In some individuals they are scarcely seen at all, in others they surpass the apatite in quantity, but even in such cases the border of the individual is a coherent frame of apatite. The borders are now even, now somewhat sinuous. There sometimes occurs a phenomenon similar to twinning; the border divides the apatite area and its only distinct angle (90°) into two equal parts, one half extinguishes parallel to the border, the other extinguishes at an angle of about 30° with it. The border is visible only between crossed nicols, being then very distinct. It is quite rectilinear. (See fig. 16.)

In one slide there are several angular lumps of magnetite reaching a length of up to some mm, they often contain some hornblende. Very small lumps are included in apatite. The rock changes into a bulk of magnetite and feldspar, quite similar to the one described p. 37. Also here there occurs much apatite, partly of the above described type, partly in the form of compact crystals, often concentrated in streaks with a breadth of up to 1 cm. There is also seen uralite in the shape of long rays, as is already described above. Very tiny grains of a pleochroic mineral, rather like orthite, are enclosed in the uralite crystals. Small plates of biotite also occur.

A slide of a variety containing much very irregularly distributed magnetite shows the following. Numerous feldspar phenocrysts with titanite and biotite,

but without any magnetite inclusions, are lying in a groundmass, consisting mainly of medium-sized feldspars and magnetite, generally quite similar to the mixture of these two minerals, described above and p. 38. Sometimes, but rather seldom, it resembles the normal porphyry groundmass. Transitions between these different types occur. Besides there are found uralite, biotite and apatite. With regard to the structure this rock evidently stands between the normal porphyry and the nodules.

Dikes of dark syenite.

Distribution and mode of occurrence.

These dikes occur very sparingly in the syenite west of Geologen at a distance of 300 to 400 meters from the ore. They run nearly parallel to the general direction of strike of the region. The greatest width observed is somewhat more than 1 meter; the dikes send out numerous apophyses, which generally follow the jointing planes of the syenite and are closely grown on to it, their width often amounts to only a few cm. Within a few very limited areas, the syenite is completely interwoven with such small dikes.

Macroscopic characters.

In the middle of a dike the rock is of a dark grayish brown colour and for the rest very much resembles the fine-grained, porphyritic phases of the syenite. Near the border, it grows darker, blackish gray, the phenocrysts disappear and the groundmass grows dense. The rock of small apophyses has always this appearance.

Microscopic characters.

The rock from the middle of a dike shows, even under the microscope, great likeness to the fine-grained syenite. It consists principally of feldspar, moreover of hornblende, magnetite, titanite and apatite, and epidote due to the weathering. The percentage of dark minerals and apatite is somewhat higher than is usual in the syenite. The feldspar is microperthite; the plagioclase component is often polysynthetically twinned (albite law) with broad lamellæ. The hornblende is fibrous. The magnetite occurs in the shape of crystals or in rows of crystals, which sometimes form crosses and triangles, probably some kind of

crystal skeletons. The epidote occurs in big lumps with a weak pleochroism. The broadly lamellated plagioclase is probably rich in CaO, and has supplied most of the material for the development of the epidote.

A slide of the contact with the syenite shows the following features. The dike rock consists of feldspar and of magnetite in a considerable quantity. The feldspar generally occurs in sphærulites with a diameter of 0,1 to 0,2 mm; the width of the different rays constituting the sphærulite cannot be determined but is sure to be very inconsiderable. In some places it occurs as optically homogeneous individuals with a microperthitic intergrowth, but otherwise having the same form and size as the sphærulites. The magnetite is found in small crystals between these microperthite individuals. The latter are very probably recrystallized feldspar sphærulites. The contact is very well defined, and the syenite shows no contact phenomena.

Dikes of syenite-porphyry.

Distribution and mode of occurrence.

In the whole district, rocks of this kind occur only on Kiirunavaara, orming a series of dikes, generally running east and west. They intrude the syenite and the porphyries closely related to it (»older porphyries») and are consequently of a later date than these; some of them are older than the great ore body, some are younger. The only occurrence that has been noticed in contact with dark syenite dikes turns out to be younger than these. The contacts are often somewhat sinuous, but always very distinct.

The different occurrences are indicated on the accompanying map where their directions are clearly shown.

No. 1. Uncovered to a width of a few meters, shows contact with fine-grained syenite.

No. 2 is in its most western part easy to discover, it is a few meters wide and encloses angular fragments of the adjacent fine-grained syenite. A little more eastwards it also encloses fragments of porphyry.

No. 3 is about 10 meters wide; it is rather probable that it extends somewhat further west than is shown on the map, though covered with morainic matter.

No. 4 can from its most westerly outcrop be followed at least 170 meters eastward and at last bends towards the north. It is probably connected with No. 4 A [1].

[1] The area between is covered with moraine containing numerous boulders of dike-porphyry, and nowadays also in part with dumps from the adjacent open cuts.

No. 5 outcrops with a width af 20 meters, but the northern contact is covered, it is therefore probable that the actual width may be somewhat greater. To the west it divides into at least three branches, in places hardly 1 meter wide. Along the contact it encloses some fragments of the wall rock.

No. 6. Under this number are included three outcrops of dike porphyry, of which, however, perhaps only the two most easterly ones are connected.

No. 7 is about 8 meters wide and intrudes medium-grained syenite, enclosing some fragments of it, it also cuts a system of small dark syenite dikes.

No. 8[1] is 8 meters wide, it is exposed for a length of only a few meters, striking probably east-west.

No. 9[1] is hardly 1 meter wide and is exposed for some meters only.

No. 10. This considerable mass begins in the most westerly part as small dikes (in places only a few cm wide) in the »older porphyries», but very quickly it spreads out to a width of at least 45 meters and, keeping the same width, runs for about 120 meters eastwards. It encloses fragments of the wall rock; the northern contact is visible in several places. the south one is covered. To the east the great mass suddenly divides into a system of small dikes and veins just as at its western end, (see also No. 5!). Part of it is covered here, but it is scarcely to be doubted that these dikes are connected with the sheet of similar porphyry which forms the foot wall of the ore at the middle of the contact in Geologen.

The great sheet No. 11 is bordered on the east by the ore and on the west by a zone of »ore-breccia»,[2] i. e. dikes and veins of ore enclosing angular or rounded porphyry fragments in great quantities. As far as I have been able to ascertain, all the rock between these two boundaries belongs to the dike porphyry, but I have failed in my attempts to find out whether No. 11 is connected with any of the above described dikes, for instance No. 4 (or may be, before the formation of the ore, No. 10).

No. 12 is in one respect very different from the above described

[1] No. 8 is located a little west of the great quartz-porphyry dike west of Geologen, No. 9 some hundred meters more to the south-east.

[2] The Swedish word »malm-breccia», (ore-breccia) has consistently been used as well in the scientific literature [S. G. U. e. g. ser C. No. 183 (The ore-district of Jukkasjärvi.)] as in the mining-districts.

occurrences. Those in contact with the ore (Ns. 10 and 11) are penetrated by dikes and veins of ore and hornblende, often in such an abundance as to form a veritable ore-breccia, as is the case at the western contact of No. 11; the porphyry, on the contrary, never inserts branches into the ore body.

N:o 12 on the other hand very plainly proves to be younger than the ore body, cutting across it almost right up to the hanging wall and enclosing a few fragments of ore, some of which reach a length of several meters. The distribution of these inclusions is very irregular. The dike inserts one little branch into the ore to the south, and at a level 15 meters lower, near the hanging wall, another branch, 8 meters wide, to the northeast. The dike has also been met in the open cuts, causing much trouble by its great bulk, as it is more than 20 meters wide. The dip varies a little, it is generally southerly and steep. It is probable that No. 11 is connected with No. 5, but as a great part of the area between is covered with earth, this question is rather difficult to settle.

No. 13 is also obviously younger than the ore, intruding it at the hanging contact. Of about the same age is a narrow dike in western Geologen.

The relations of the occurrences Ns. 10—13 to the ore and to the quartz-porphyry will be more closely discussed in a following chapter.

A morainic boulder of dike porphyry found some hundred meters west of Statsrådet shows that dikes of this type occur even further to the south.

Macroscopic characters.

The rock is porphyritic with numerous feldspar phenocrysts, which generally constitute one-fourth to one-third of the whole mass. These phenocrysts vary in size from 2 to more than 10 mm in diameter and are of a white or, more seldom, pinkish colour. Especially the bigger ones are round in shape, and the intergrowths of rectangular individuals being such a characteristic feature of the »older porphyries» almost never occur. This difference is very obvious, especially on a weathered surface, a fact that highly facilitates mapping work. Nevertheless, a good deal of practice is needed in order to be able to distinguish the two different types of porphyry for certain in the field. Beside the feldspars, badly idiomorphic single phenocrysts of green silicates (augite and hornblende) are seen.

The groundmass is very fine-grained, to the naked eye often dense, it is generally of a whitish gray colour, more seldom grayish green, rather similar to that of phonolite, dark-gray or reddish.

The rock lacks nodules of the type which is so common in the »older porphyries», only in a few places (in Ns. 10, 11 and 12), some irregular concentrations of hornblende occur. Besides there are seen in Ns. 10 and 11 drusy pockets similar to miarolitic cavities. But veins of hornblende and titanite, seldom more than 1 mm wide, often occur. In the immediate neighbourhood of the contact with the wall rock the phenocrysts are less numerous and smaller, and the groundmass is more dense and dark.

Microscopic characters.

Feldspar phenocrysts. The feldspar phenocrysts are perthitic just as those of the »older porphyries», but the plagioclase component is always predominant. It is often polysynthetically twinned with very thin lamellæ, the twinning sometimes being visible in spots only. The fine and somewhat irregular twinning according to the combined albite and pericline laws, which is often met with in the syenite and in the older porphyries, is also here a common feature. But the Mannebach twins of the former are never seen. Zonal structure often occurs and the centre of the individual is then broadly lamellated, the periphery thinly or not at all. As shown by the analyses, the plagioclase is oligoclase-albite, probably with only small quantities of the anorthite molecule. The potash component forms thin laths in the peripheric parts of the plagioclase, zonal accumulation sometimes occurs just inside the border of the latter. It differs from the plagioclase by lower single as well as double refraction.

The phenocrysts are generally composed of numerous, sometimes as many as 10, microperthite crystals with different orientation and very irregular limits between the different individuals. The outlines are generally rounded, but triangular points often stick out. Their sides form an angle of 60° to 70°; when the albite lamellæ are visible, they run at right angles to the longitudinal direction. From this we conclude that the bordering crystal faces are (110) and $(1\bar{1}0.)$ The angle is sometimes blunt, evidently through the development of the pinacoid (010). These features remind one much of the »Rhombenfeldspäte» of anortoclastic constitution. On other crystals the pinacoid (010) is much better developed. A radial arrangement of the different individuals of a compound phenocryst is rather uncommon. The shape of some phenocrysts denote a relatively calm crystallization, as they otherwise would have been fractured during the movements of the magma. The idiomorphism is generally good, but somewhat uneven borders sometimes occur.

In that part of the dike mass No. 10, which extends immediately west of the ore, phenocrysts of another type occur beside those above described, the latter, however, are more abundant. These phenocrysts are not perthitic, but polysynthetically twinned (the albite law) with extremely thin lamellæ. Even when they are subject to a 400-fold magnification, the twinning is often seen only with the greatest difficulty. A sometimes rather indistinct lamination at right angles to the above mentioned, probably according to the pericline law,

also occurs. The phenocrysts reach a length of 0,4 to 0,7 mm and have the shape of rectangles or squares. The idiomorphism is good. Judging from the optical properties, soda-microcline is very probably present, but the writer has not been able to find positive evidence of this. Intermediate forms between this type and the one before described are sometimes seen. Similar, but much smaller and not porphyritic feldspars occur in the other dikes as well.

As inclusions in the first described type of phenocrysts now and then occur magnetite, augite (see next section), hornblende and skeleton titanite, the last-mentioned on the whole more seldom than in the »older porphyries». Epidote, muscovite, calcite and some biotite are probably all products of alteration. They are occasionally accumulated in the centre of the phenocrysts but are of no importance as regards quantity.

The phenocrysts of the second type are generally free from inclusions of any kind.

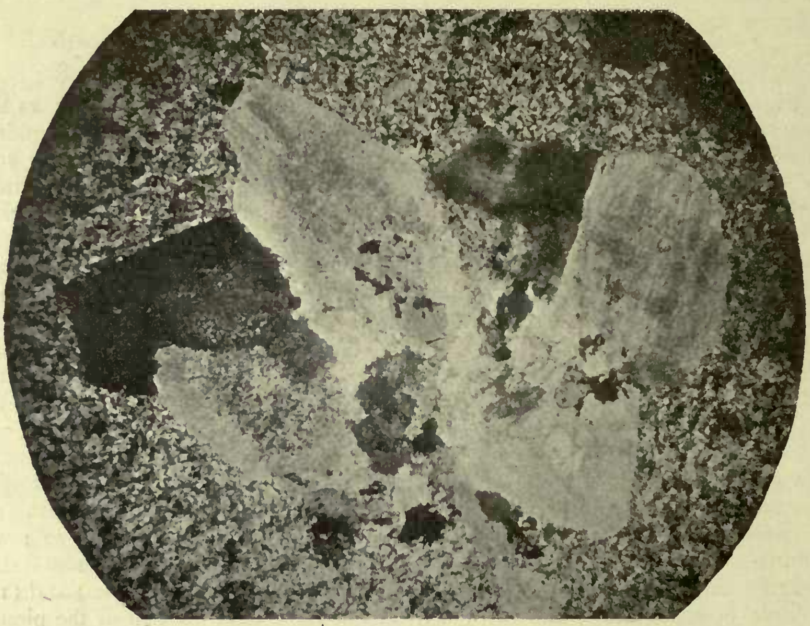

Fig. 17. Compound microperthite phenocryst in syenitic dike-porphyry, Kiirunavaara. Nic. +. Magn. 14 times. Some small patches of magnetite and of hornblende are enclosed in the feldspars.

Augite and uralite-phenocrysts. The augite is optically quite similar to that of the syenite, though it has perhaps a more vivid colour (pale green) than the latter. The phenocrysts are seldom more than 1 mm long and are thick prisms with a slight idiomorphism, often twins with intercalated thin lamellæ. They are sometimes quite surrounded by groundmass but are often found in a feldspar phenocrysts. These included augites often consist of numerous separated, but optically equally orientated parts, mostly located on the boundaries between the different feldspar individuals composing the phenocryst. This peculiar intergrowth is analogous to the form of the augite in the syenite. The uralitisation is far less spread than in the »older porphyries», most augites

are only slightly affected, but its progress is quite similar to that above described.

As inclusions occur: apatite, magnetite, zircon (with pleochroic »Höfe»), titanite as usual. Epidote is sometimes present in abundance, probably a product of alteration.

The groundmass. The groundmass consists chiefly of feldspar, but augite and hornblende sometimes constitute more than one-third of the whole of it. Titanite and now and then biotite also occur, further quartz, magnetite, apatite, zircon, calcite and epidote,

The feldspars form isometric grains with sinuous borders towards one another, they generally have a diameter of 0,1 to 0,2 mm, but in the neighbourhood of the ore, i. e. west of Geologen and Grufingeniören, their diameter is but a few hundredths of a millimeter. They are often coarsely perthitic in a distinct way with a considerable percentage of potash-feldspar, which has thus been concentrated in the groundmass. The plagioclase component seldom shows lamination and then resembles the last described type of feldspar phenocrysts. These feldspars too are little altered.

The augite resembles the phenocrysts in its optical properties, it is more or less transformed into uralite. Also some feldspar substance has then been replaced by hornblende (»gewanderte Hornblende»). The irregular grains of augite and the bunches of hornblende seldom reach more than 0,1 to 0,2 mm in length.

Quartz occurs sparingly and in small grains.

Magnetite is of much less importance here than in the »older porphyries», as in shown by the calculation of the analyses. If correction is made for the entering of TiO_2 into the titanite molecule and for the presence of some FeO in the silicates, the percentage of magnetite amounts to about 2,5 respectively 1,2 in the two analyses calculated according to the american system. It appears in the shape of very tiny crystals or concentrations of crystals, sometimes (ilmenite?) wrapped in titanite.

Apatite is very sparingly present, zircon occurs sparingly too, as a rule, but it is abundant in the pink variety of dike No. 12. The crystal forms are prisms and pyramids, the idiomorphism is very good and the length 0,1 mm at the most.

Titanite is not as common as in the »older porphyries» and the individuals are often smaller, scarcely reaching a length of 1 mm. The form is the same. Sometimes an individual has been found lying partly in a feldspar phenocryst, and partly in the groundmass beyond it. Its relations to the augite, hornblende, magnetite, ilmenite and apatite are the same as in the »older porphyries». The thin veins of titanite are already described; a genetically similar phenomenon is probably the occurrence of thin rays of titanite with the same optical orientation and forming rows. The groundmass between these titanite particles is curiously enough quite fresh and has no visible fissures.

Biotite and calcite are present in considerable abundance in part of No. 10 and most often form rings together round the feldspar phenocrysts, but occur as well equally distributed all through the groundmass. (Augite and hornblende do not occur here.) The biotite is similar to that of the »older porphyries». The specimen is taken in a place where even the latter show similar characters, for which reason may be supposed that the formation of these minerals is a rather late metamorphism, caused by pressure or thermal action. The first is more likely, as a zone of pressure seems to be running parallel to the ore in the most northerly part of Kiirunavaara, accentuated by a faint shistosity in the

porphyries. Calcite is moreover seen in nearly all slides in the shape of irregular grains, it is evidently the holder of the sometimes considerable percentage of CO_2 of the rock, which reaches its maximum, 1,40 per cent, in analysis No. IX. STUTZER [62 p. 596] has in the same dike seen calcite which he considers a primary constituent. The calcite being found at the side of limpid plagioclases is to him a proof of the magmatic origin of the former. The writer cannot agree with him, but it is not improbable that the formation of the calcite is almost coincident with the solidifying of the rock and that it thus should be of thermal origin.

Endomorph contact metamorphism. A slide cut through the contact of dike porphyry with fine-grained syenite shows in the former a few small plagioclase phenocrysts of narrow rectangular form with their longitudinal axis parallel to the contact. Titanite occurs as usual. There are parallel nodule-like streaks, reaching a width of about 2 mm, and composed of clear broadly lamellated plagioclase, hornblende, titanite and magnetite. The boundaries of these nodules towards the groundmass are indistinct. By the direction of the phenocrysts, the magnetite concretions and the nodules a well developed flow-structure appears, always running parallel to the contact. Stripes of magnetite and even feldspar phenocrysts sometimes bend about the nodules.

The contact is very distinct even under the microscope, the syenite shows neither crushing nor contact phenomena.

Nodules. Except those above described, nodules are seen in dike No. 12 and in that part of No. 10 which is adjacent to the ore. In the former small irregular quartz phenocrysts occur, which grade into elongated lenses having a length of up to 1,5 mm, and chiefly composed of some quartz grains with uneven borders towards the groundmass, but even ones towards each other. Much titanite also occurs, generally in single individuals, cementing the quartz grains and often including one of them. Some feldspar similar to that of the nodules of »older porphyries» is also seen, and some hornblende. The nodules of No. 10 are less well developed.

Some remarkable variations. At the south contact of dike No. 5 there occurs a peculiar border zone, about 1 meter wide, with very distinct outlines towards the rest of the dike. It also runs along one side of at least one of its western branches. The groundmass is in this particular zone pale green, otherwise it is more grayish in this dike. The feldspar phenocrysts on the contrary have their usual appearance. The border is almost as distinct under the microscope as when seen macroscopically. Hornblende and epidote (both in small grains) are present in abundance in the groundmass of the green zone, and this is evidently the cause of the different colour. Supposing that the hornblende is a primary constituent of the rock, the difference between the border zone and the rest of the dike is also primary and caused by magmatic differentiation. The epidote is namely chiefly to be considered as a product of the alteration of the hornblende.

In the groundmass of No. 10 some peculiarities have been observed, which are of importance for the discussion in a following chapter. The size of grain of the groundmass diminishes continuously as you go farther to the east and is only 0,01 to 0,02 mm in the part immediately west of the ore. At the same time, the feldspar phenocrysts of the second type develop.

Dike No. 12 shows an irregular alternation of a reddish and a green variety. Under the microscope the former shows a good deal of zircon crystals, with red pigment around them; the latter shows a considerable quantity of hornblende in the groundmass. See also analyses Ns. IX and VIII.

In No. 10 there are seen a few veins, only some cm wide, of a reddish, dense rock. The microscopic examination shows it to be a feldspar rock with suddenly varying size of grain. The feldspar is partly plagioclase, partly microperthite. Magnetite is abundant along the contact.

Chemical characters.

Four analyses have been made on this group of porphyries, No. VII by R. Mauzelius, Ns. VIII, IX and X by K. Schröder.

	VII	VII a	VII b	VIII	VIII a	IX	IX a	X	X a	X b
SiO_2 . .	67,79	1123	72,94	67,81	1123	69,00	1142	63,82	10,57	67,86
Al_2O_3 .	15,29	150	9,72	14,93	146	14,54	143	14,81	145	9,31
Fe_2O_3 .	1,05	6		1,42	9	0,86	5	1,63	10	
FeO . .	0,59	8	1,39	0,80	11	0,49	7	1,25	17	2,42
MnO .	0,06	1	0,06	0,06	1	0,03		0,07	1	0,07
MgO . .	1,70	42	2,74	1,71	42	0,40	10	3,48	86	5,53
CaO . .	3,03	54	3,52	2,83	51	2,12	38	5,26	94	6,03
BaO . .	0,06			n. d.		n. d.		n. d.		
Na_2O .	6,89	111	7,20	6,45	104	4,42	71	6,37	102	6,58
K_2O . .	2,79	30	1,92	3,01	32	5,83	62	2,78	29	1,89
H_2O + .	0,23	13		0,30	17	0,50	28	0,20	11	
CO_2 . .				0,28	6	1,40	32	0,25	6	
TiO_2 . .	0,63	8	0,51	0,78	10	0,47	6	0,38	5	0,30
P_2O_5 . .	0,02			0,02		0,01		0,02		
S . . .	0,01			0,07	2	trace		0,01		
Sum	100,14			100,47		100,07		100,33		
H_2O — .	0,08			0,05		0,12		0,06		

No. VII. Dike No. 4. The middle of the dike about 60 meters E of ist most western outcrop.

No. VII a. The molecular proportions of No. VII, multipl. by 1000.

No. VII b. The same, calculated on a sum of 100, free from H_2O and CO_2, all Fe as FeO.

No. VIII. Dike No. 12. Variety with greenish-coloured groundmass.

No. VIII a. See No. VII a.

No. IX. Dike No. 12. Reddish variety.

No. IX a. See No. VII a.

No. X. Dike porphyry area No. 11.

No. X a. See No. VII a.

No. X b. See No. VII b.

American system.

No. VII.		*Norm.*		
Quartz	SiO_2	10,39	Q 10,39	Sal 88,14
Orthoclase . . .	$K_2O . Al_2O_3 . 6\ SiO_2$	16,77	F 77,75	
Albite	$Na_2O . Al_2O_3 . 6\ SiO_2$	58,47		
Anorthite . .	$CaO . Al_2O_3 . 2\ SiO_2$	2,51		
Diopside . . .	$CaO . SiO_2$ 4,89 $MgO . SiO_2$ 4,23	9,12	P 9,47	Fem 11,72
Wollastonite . .	$CaO . SiO_2$	0,35		
Magnetite . . .	$FeO . Fe_2O_3$	0,23	M 2,25	
Hematite . . .	Fe_2O_3	0,80		
Ilmenite	$FeO . TiO_2$	1,22		

Sum 99,86 + H_2O etc. = 100,18.

Class 1 Persalane, Subclass 1 Persalone, Order 5 Canadare, Rang 1 Nordmarkase, Subrang 4 *Nordmarkose.*

No. X.[1]		*Norm.*		
Quartz	SiO_2	4,47	Q 4,47	Sal 78,31
Orthoclase . .	$K_2O . Al_2O_3 . 6\ SiO_2$	16,21	F 73,84	
Albite	$Na_2O . Al_2O_3 . 6\ SiO_2$	53,73		
Anorthite . . .	$CaO . Al_2O_3 . 2\ SiO_2$	3,90		
Diopside . . .	$CaO . SiO_2$ 9,31 $MgO . SiO_2$ 8,06	17,37	P 18,37	Fem 21,45
Hypersthene . .	$MgO . SiO_2$ 0,60 $FeO . SiO_2$ 0,40	1,00		
Magnetite . . .	$FeO . Fe_2O_3$	2,32	M 3,08	
Ilmenite	$FeO . TiO_2$	0,76		

Sum 99,76 + H_2O etc. = 100,24.

Class 2 Dosalane, Subclass 1 Dosalone, Order 5 Germanare, Rang 1 Umptekase, Subrang 4 *Umptekose.*

Osann's system.

	s	A	C	F	a	c	f	n	k
VII	73,45	9,12	0,60	7,11	11	0,5	8,5	7,9	0,93
X	68,16	8,47	0,84	13,21	7,5	1	11,5	7,7	1,10

[1] The CO_2 content is not included, as this oxide probably is no primary constituent of the rock.

Analyses Ns. VII and VIII are very similar to one another, but it is rather strange, that No. VIII and No. IX show such a different ratio $K_2O : Na_2O$. The specimens analyzed (Ns. VIII and IX) are collected only a few meters from one another. Analysis No. X, on the other hand, has a more basic character, exclusively on account of the high percentage of MgO and non-anorthitic CaO.

The analyses very plainly show the characteristic feature of these porphyries, that the magnetite is always inferior in quantity to the dark silicates. The ratio P:M is 4,2 (No. VII) and 6,0 (No. X), while it in no other analysis exept No. XI reaches the value 1,0. I must hold forth, however, that the fact that TiO_2 mainly is a constituent of the titanite molecule, but in the calculation of the norm is combined with FeO to form ilmenite, to some extent changes the case to the ad vantage of M. This error is, however, at hand in about the same degree in all the analyses.

Osann's quantities as compared to the types given by him, show the following. No. VII is nearest to the trachyte type Garkenholz and the dacite Porobbo, both belonging to »Erste Vertikalreihe». The relation is shown on the following table.

	s	a	c	f
No. VII	73,5	11	0,5	8,5
Garkenholz	69	11	0,5	8.5
Porobbo	75,5	12	1	7

No. X on the other hand does not resemble any of Osann's »Ergussgesteine», it fills a gap in the »Erste Vertikalreihe», after Garkenholz. It is on the contrary related to the type Kammgranit.

	s	a	c	f
X	68	7,5	1	11.5
Kammgranit	68	6,5	1	12,5

Comparison to the »older porphyries».

The rock differs from the older porphyries in the larger dimensions of the feldspar phenocrysts and in their being composed of several microperthite individuals, in the slight uralitisation of the augite, the almost total absence of nodules, the finer grain of the groundmass and the low percentage of magnetite. The rather great quantity of quartz is due to the high percentage of SiO_2

Luossavaara.

Exposures. Kinds of rock.

On Luossavaara, the rocks of the syenitic group outcrop on the summit and are well exposed within an area of about 300 meters' length in an almost north-southerly direction, and of about 150 meters' width. Moreover there are found scattered outcrops and prospecting diggings in several places out of this area, there are especially many but small outcrops on the northwestern slope. All the rocks belong to the syenite-porphyry group (the »older» porphyries); real syenite does not occur, nor any dike rocks of syenitic or of any other composition. Syenite may perhaps be present farther down the western, moraine-covered slope of the mountain.

Syenite-porphyries.

Macroscopic characters.

The porphyries are rather similar to those of Kiirunavaara, but phases with large feldspar phenocrysts are not as common as there, and nodular structure is more rare. On the whole the rocks of Luossavaara have a somewhat more femic character.

Varieties with relatively small feldspar phenocrysts in a fine-grained groundmass of a gray, grayish green or reddish colour, sometimes with hornblende nodules, are widely distributed. A type with a dark gray groundmass, evidently rich in magnetite, is also very common. The magnetite is sometimes unequally distributed with the result that the rock

becomes irregularly banded with streaks rich in magnetite alternating with such as are almost free from it. Such streaks are only 1 or a few mm wide. Especially on the northern slope there are gray porphyries similar to those of northern Kiirunavaara. Magnetite and titanite nodules sometimes occur, especially in rather dark-coloured varieties. Near the ore there are often seen pinkish feldspar rocks with aggregates of magnetite crystals.

Microscopic characters.

Even under the microscope these rocks are very similar to those of Kiirunavaara and a minute description would mostly be a reiteration of what has already been said of the latter.

The plagioclase component of the feldspar phenocrysts is often »striped», the potash-feldspar is a minor constituent. The groundmass-feldspars are also often »striped», they are somewhat elongated and generally reach a length of about 0,1 mm. Now and then a beautiful sphærulitic arrangement occurs; part of the groundmass forms quite regular sphærulites with a diameter of 0,2 to 0,3 mm, otherwise, an irregular shadowing appears between crossed nicols. The size of the feldspar individuals composing these sphærulitic groups cannot be distinguished. Augite is not found, but the hornblende generally resembles uralite. This mineral and titanite and apatite occur as a rule in the same way as in the rocks of Kiirunavaara; small plates of biotite are sometimes abundant, rather often concentrated in streaks. This mica is perhaps of secondary origin.

As stated above, these rocks often have a more femic character than the bulk of the rocks of Kiirunavaara. This fact is shown mostly by the abundance of magnetite, which often makes up about 10 per cent of the volume of the rock and sometimes even more, while dark silicates scarcely are found in a greater quantity in these than in the more salic varieties. The magnetite occurs in small crystals, most often scarcely reaching a size of 0,1 mm, and is now equally distributed, now concentrated in patches or bands as is the case in the above described banded porphyry. It is often concentrated in small, scarcely 1 mm long angular lumps, surrounded by a zone free from magnetite. There also occur rows of single crystals, bordered by zones free from this mineral (see p. 18) they are probably akin to the thin veins which are described later on. As some rather big lumps are surrounded by titanite, it is not impossible that also ilmenite sometimes is present.

As mentioned above, the nodules are much less important in these rocks than in those of Kiirunavaara. The microscopic examination shows, however, that small and rather irregular nodules are not very uncommon. They consist chiefly of titanite, feldspar and magnetite, and are often very elongated, sometimes branching out into irregular shapes. They are generally compact, showing indistinct outlines towards the groundmass, and are thus to be considered as »embryonal». The big and well defined nodules, which macroscopically resemble those of the Kiirunavaara rocks, correspond in nearly all respects to the latter even under the microscope.

The thin veins, consisting chiefly of magnetite, often contain feldspars like those of the nodules. These veins are often more like very elongated nodules than filled fissures.

Chemical characters.

Of the syenite-porphyry of Luossavaara one analysis has been made by R. MAUZELIUS. The specimen analyzed is a gray porphyry with small hornblende nodules, which occurs on the northern slope of the mountain. It is an example of the considerable predominance of dark silicates over the magnetite, which phenomenon, as is already mentioned, is very rare in the »older» porphyries.

	XI.	XI a.	XI b.
SiO_2	61,24	1014	66,23
Al_2O_3	13,95	137	8,92
Fe_2O_3	3,81	24	
FeO	1,45	20	4,41
MnO	0,14	2	0,14
MgO	4,23	106	6,84
CaO	3,69	66	4,30
BaO	0,05		
Na_2O	5,13	83	5,39
K_2O	4,53	48	3,12
H_2O +	0,38	24	
CO_2	0,51	12	
TiO_2	0,82	10	0,67
P_2O_5	0,01		
S	0,02		
Sum.	99,96		
H_2O —	0,09		

No. XI a. The molecular proportions of No. XI, multipl. by 1000.
No. XI b. As above, calculated on a sum of 100, free from H_2O and CO_2, all Fe as FeO.

American system.

No. XI		Norm						
Quartz	SiO_2		3,08	Q	3,08	Sal	75,32
Orthoclase	$K_2O . Al_2O_3 . 6 SiO_2$		26,83	F	72,24		
Albite	$Na_2O . Al_2O_3 . 6 SiO_2$		43,74				
Anorthite	$CaO . Al_2O_3 . 2 SiO_2$		1,67				
Diopside	$CaO . SiO_2$	6,98	13,03	P	17,57	Fem	23,79
	$MgO . SiO_2$	6,05					
Hypersthene	$MgO . SiO_2$		4,54				
Magnetite	$FeO . Fe_2O_3$		2,78	M	6,22		
Hematite	Fe_2O_3		1,92				
Ilmenite	$FeO . TiO_2$		1,52				

Sum 99,11 + H_2O etc. = 100.08

Class 2 Dosalane, Subclass 1 Dosalone, Order 5 Germanare, Rang 1 Umptekase, Subrang 4 *Umptekose*.

Osann's system.

	s	A	C	F	a	c	f	n	k
No. XI	66,90	8,51	0,41	15,28	7	0,5	12,5	6,4	1,00.

This rock is not very similar to any of OSANN's types.

Magnetite dikes.

Mode of occurrence. Macroscopic characters.

The occurrence of dikes and veins of magnetite ore is very characteristic of these porphyries, especially of the more femic ones. These dikes and veins are chiefly seen in the claim of Minerva, 50 to 150 meters west of the summit of the mountain (which is an outcrop of the great ore body) and in a zone extending in a northeasterly-southwesterly direction from there. The rocks are entirely interwoven with such dikes and veins with a thickness varying from a few mm to 5 meters. The last measure, however, has been observed only in one dike at the southern slope of the mountain, which runs almost parallel to the great ore body at 20 meters' distance from it. In its mineralogical composition, however, it is more similar to the other dikes than to the main ore mass. Dikes more than 1 meter thick are rare. Their course is occasionally straight but generally winding; the contacts with the wall rock are generally very well defined, especially when the latter is low in magnetite. Sometimes, however, they are closely surrounded by a kind of rock very rich in magnetite. There are also seen isolated small schlieren and lumps of ore, sometimes resembling large nodules.

The magnetite is beyond comparison the most important constituent. It is coarsely crystalline and almost black in colour. In small cavities badly developed octahedrons are seen. Titanite occurs always, often in a large quantity, now as tables, some cm long but only a few mm thick, now as almost idiomorphic crystals with a length of a few mm. It is often concentrated in drusy lumps, almost similar to the titanite nodules in the porphyries. Quartz is generally present, sometimes in large drusy

masses. Together with hematite in great crystal plates it also occurs as rather small and irregular vein masses associated with the magnetite dikes. Biotite also occurs; green chlorite in small flakes is sometimes rather abundant. A bright red feldspar is sometimes seen at the border towards the wall rock. Green, fibrous hornblende is common.

Small cross-cracks filled with calcite are very often seen. In small veins these fissures run right through the magnetite and continue for some way in the wall rock on both sides. In the larger dikes they are seen at the two contacts and from there extend only very little on both sides.

Concerning the possible relation of some of the dikes to the great ore body, see p. 120.

In the rocks rather rich in magnetite there are generally very thin veins, sometimes less than 1 mm wide, consisting of magnetite, apatite, titanite and hornblende.

Microscopic characters.

A slide from the rock west of the summit, which is interwoven with countless small magnetite veins, shows the following. The rock is rather rich in magnetite, but contains only small amounts of dark silicates. The magnetite is not found in the groundmass immediately adjacent to the veins, which are winding and sometimes disappear quite suddenly. Their outlines towards the groundmass is dependent on the crystal faces of the magnetite. They branch off into rows of crystals which sometimes pass into the magnetite grains of the groundmass. Beside the magnetite the veins contain feldspar, with the usual habit of the nodule-forming mineral, some biotite and titanite. Quartz is also present, filling fissures.

The almost black streaks with a width of up to 1 cm, which surround some small magnetite dikes in the claim of Minerva, consist chiefly of magnetite in well developed crystals with a diameter of about 0,1 mm. These crystals cohere over large areas, and in the small angular spaces between are seen feldspars like those of the groundmass of the normal ådjacent porphyry. These magnetite masses are connected with the dike.

Beside the magnetite, which is the quantitatively predominant constituent of the larger dikes, there is also seen titanite, biotite, often altered to chlorite and quartz. The titanite and biotite are generally bordered by the magnetite crystal faces; when found together neither is idiomorphic. The crystal forms of the titanite are well developed only in druses. The quartz forms grains about 1 mm in length with a peculiar undulatory extinction, it appears to be composed of numerous, not quite parallel rays. It fills various druses and cavities in the ore mass and encloses sharply idiomorphic titanite crystals, sometimes also small flakes of biotite or magnetite crystals. The biotite is often abundant in the wall rock in the immediate neighbourbood of the ore dikes.

As to the origin of these magnetite dikes, see p. 151.

Apatite veins.

Veins of apatite occur only in some places, partly at the northern end of the main group of exposures, partly on the northwestern slope of the mountain. They are very short, reach a width of about 1 dm, and consist of white or greenish, finely crystalline apatite, sometimes with small red spots. They enclose fragments of porphyry. All contacts are well defined.

The microscopic examination shows that the apatite occurs in thick prisms, 0,2 to 1,5 mm in length. Small plates of red hematite (»Eisenglimmer») are enclosed in the apatite crystals or occur between them. Some very small quartz grains lie between the apatites. Titanite occurs in skeleton individuals some mm in diameter, enclosing prisms of apatite.

Exposures between Luossavaara and Hopukka.

Distribution of exposures. Kinds of rock.

Rocks belonging to the syenitic group are exposed on Luossavaara only for about 280 meters north- northeast and 550 meters northwest of the summit. They are then covered with thick moraine for an extent of about 1200 meters in the former direction, but then outcrop again for about 600 meters, almost up to Nokutusjärvi. The limit between these rocks and the quartz-porphyry runs in a north-northeasterly direction. The contact is nowhere exposed. The maximum width of this area of outcrops of syenitic rocks is about 200 meters. All the various types belong to the syenite-porphyries and are akin to those of Luossavaara and to the »older» porphyries of Kiirunavaara. In this area, howewer, there also occurs in abundance a type of rock rather rare in the districts before described, viz. a variety composed chiefly of feldspar and magnetite, the latter occurring in great quantities. As this rock requires a very minute description it will be treated (under the name of *magnetite-syenite-porphyry*) separately in the following. It occurs in the western parts of the area in a zone, reaching a width of 50 to 75 meters at the utmost.

Normal syenite-porphyries.

Macroscopic characters.

These rocks generally contain a few rectangular feldspar phenocrysts lying in a fine-grained or dense groundmass of a gray, grayish red or pinkish colour, as a rule without visible nodules. They are more salic than the rocks on Luossavaara but are otherwise rather similar to them.

They are often interwoven with thin, chlorite-coated fissures, getting thus quite brecciated.

Small strings of calcite with scattered grains of pyrite and chalcopyrite also occur. Veins of finely crystalline apatite are rare; they reach a width of more than 1 dm. At a distance of 140 to 160 meters from the border of the quartz-porphyry, there occurs a phase, somewhat different to the other ones. It has numerous feldspar phenocrysts up to 1 cm in length, and phenocrysts of hornblende, in a dense groundmass of a grayish brown colour.

The variations between the different types always have the characters of continuous transitions. There appears to be no very great change near the border to the quartz-porphyry. The tuff-like mass, chiefly consisting of rocks belonging to this group, which occurs in the westernmost parts of the quartz-porphyry, is described p. 137.

Microscopic characters.

Feldspar phenocrysts. The feldspar phenocrysts consist of plagioclase without any perthitic intergrowth of potash-feldspar. They are 1 to 10 mm long with a rather good idiomorphism and have the usual shape of rather thick tables parallel to (010). They are sometimes fractured, the groundmass then having penetrated into them along the fractures; the lamellæ are then often bent. The albite lamellæ are often broad, but may also have the appearance of thin »stripes», especially in the peripheric parts of the phenocrysts. According to the view verified by the analyses, that this form of lamination is characteristic of nearly pure albite, the centre of the phenocrysts should thus contain more CaO than the borders, which should be pure albite. Twinning of the Roctourné-type occurs, as well as »cross-bars» according to the pericline law. Penetration of the kind described p. 26 often occurs and the angle is then in numerous cases about 70°. The phenocrysts are sometimes composed of several individuals, intergrown in this way. Inclusions of decidedly primary origin are very rare, but irregular lumps and skeletons of titanite, small plates of biotite, and epidote in the usual shape of small grains occur. The epidote, at least, is sure to be a product of the weathering of the rock.

Hornblende phenocrysts. These phenocrysts are missing in most phases and occur in rather great quantity only in the brownish gray rock with numerous feldspar phenocrysts. They reach a length of up to some mm. The optical properties are the usual ones. The crystals have uneven outlines and include irregular areas (»windows») of feldspar, aggregates of magnetite crystals and grains of titanite.

The *groundmass* consists chiefly of feldspar in elongated, often narrowly rectangular individuals with sinuous outlines. Their length is generally 0,10—0,15 mm. They are »striped», but sometimes contain some potash-feldspar in microperthitic intergrowth. These rocks, and still more those with a high percentage of magnetite, thus seem to be very poor in potash as is also shown by the single analysis (No. XII). Magnetite in small crystals is a constant, though

never quantitatively important constituent. It is generally equally distributed throughout the feldspar mass. Some rather big lumps, which are surrounded by a rim of titanite, may perhaps be ilmenite. Hornblende and biotite occur in much smaller quantities than the above mentioned minerals, both of them in very small individuals. Apatite is as a rule relatively abundant and occurs in elongated grains with a length of some tenths of a millimeter, often coated with titanite. The titanite is a constant constituent and occurs as usual.

Nodules are seldom seen and are generally small and compact. They consist chiefly of microperthite feldspar and titanite, the former generally forming a ring around an individual of the latter, which partly also cements the feldspars. In some nodules there is much quartz, it is evidently younger than the titanite and the feldspar, which often are beautifully idiomorphic towards it. It is probably infiltrated later. Apatite, magnetite, hornblende and biotite occur in varying quantities, the two silicates being minor constituents. A strongly »embryonal» character is common to all these nodules appearing as abnormal phases of the groundmass.

Magnetite-syenite-porphyry.

In this group of exposures the porphyries extremely rich in magnetite form a zone about 50 to 75 meters wide, exposed for a length of 400 to 500 meters. The zone seems to grow wider northwards. The east border runs at a distance of 80 to 100 meters from the quartz-porphyry; the rocks between and those outcropping west of the zone constitute the group described above. I must, however, emphasize the fact, that this series of rocks rich in magnetite is only a schlieric phase of the syenite-porphyries. It is connected with normal ones by all grades of transition, it contains the same characteristic feldspars (the »striped» albite) as these and shows other important features of consanguinity too. The magnetite is, moreover, even in the normal porphyries widely predominating among the dark minerals. In the most intimate schlieric alternation with the magnetite rocks there occurs a type quite corresponding to the normal porphyries, and within areas, principally consisting of these, there occur small schlieren rich in magnetite.

Macroscopic characters.

The most common phase contains relatively few and small feldspar phenocrysts in a very fine-grained groundmass of a characteristic dark gray, sometimes almost black colour. As a rule there occur only a few rather small nodules, consisting of magnetite, titanite, feldspar and very seldom a little hornblende, but in some large areas the nodular structure

is very well developed. The nodules then often make up about one-third of the volume of the rock, they are white or pinkish in colour and therefore stand out well against the dark groundmass. They are most often

Fig. 18. Magnetite-syenite-porphyry, south of Nokutusjärvi. Nat. size. Dark gray groundmass with numerous albite nodules.

compact, but druses in the centre sometimes occur, especially is this the case with the bigger ones. Shape and size vary, but neighbouring nodules are generally similar to each other in these respects. In most cases

they are ellipsoidal or nearly sphæroidal with a diameter ranging from less than 1 mm to about 1 cm. Locally they have quite another shape, being irregular, branching and even connected with one another by thin strings of the pinkish mass. The rock is sometimes quite brecciated by the abundance of such strings. Some nodules of this type reach a diameter of several cm. The outlines towards the groundmass are always very well defined, but never quite straight.

The white or pinkish mineral turns out to be feldspar, which is always the principal constituent, besides there occur magnetite, single brown crystals of titanite, rather seldom pyrite, chalcopyrite and calcite. Hornblende is almost totally absent.

Alternating with the above described rocks there occurs a pinkish coloured porphyry, similar to the normal syenite-porphyries but often having nodules and streaks of magnetite. The width of the alternating schlieren of dark and pinkish rock is often but a few cm, this banded design is sometimes very conspicuous, being best visible on a weathered surface. It follows the general direction of strike and dips towards east-southeast at an angle of about 80°.

The limits between the different schlieren are seldom very sharp. The average composition of the pinkish phase seems to differ from that of the precedent one only by a little lower percentage of magnetite. The different colour probably in part depends only on the fact that the mineral supplying the dark colour, viz. the magnetite, is gathered together in nodule-like concentrations, the groundmass thus being almost free from it. These rocks seem, however, to consist partly only of feldspar.

In the dark rock there has been found a quite small concentration of pure fine-grained magnetite, only 6 cm in length and about 1 cm in width.

Together with these rocks it would be suitable to describe those occurring north of Nokutusjärvi, between this lake and mount Hopukka. Among the syenitic rocks on this mountain, which is situated nearly 2 kilometers northeast of the above described area of outcrops, there are phases rich in magnetite which are closely related to those described above. (p. 74—77). The whole of this almost 2 kilometers long distance is covered, partly by lake Nokutusjärvi, partly by the bogs and morasses extending northwest of it and around the brook flowing from lake Syväjärvi to Nokutusjärvi. In these morasses an extensive area of magnetic inclination, extending principally west and northwest of Syväjärvi, has been discovered by J. OLSSON SPETT and K. HANNU (1898.)

The inclination is even but weak, the curve for 10° to 26° (maximum) ($K = 1{,}7\ H$) encloses an area of about 800 meters in length and 200 meters in width, at an average, with its longer axis having a northeasterly direction. This area, called the »ore field of Syväjärvi»[1] has been investigated by means of a few diamond drill holes. The examination of the cores shows its geological nature. No concentrations of ore occur, but the rocks are rich in magnetite and show a striking likeness to those described above. They are generally of a dark gray colour and contain more or less regular nodules consisting of magnetite, apatite, feldspar, biotite and occasionally pyrite. Some phases contain feldspar phenocrysts in abundance. A pinkish rock without nodules occurs in small schlieren, often with a rather well defined contact towards the gray type. The high percentage of finely distributed magnetite in the dark rock is evidently the cause of the inclination.

Microscopic characters.

Rocks south of Nokutusjärvi. The pink-coloured phases show even under the microscope a strong likeness to the normal syenite-porphyries and have transitory forms on one side to them, and on the other side to the magnetite-porphyries. The feldspar phenocrysts are finely lamellated with short lamellæ (»striped») without any perthitic intergrowth. The idiomorphism is rather good. The groundmass consists almost entirely of feldspar, which generally has the same appearance as the phenocrysts and occurs in elongated individuals with a length of 0,10 to 0,25 mm and sinuous outlines. Magnetite occurs in small crystals, sometimes in a considerable abundance. Titanite occurs in irregular grains, partly associated with magnetite; apatite is sparingly present, calcite is also seen. The nodules offer nothing of special interest.

The rocks rich in magnetite, with well developed nodules, contain feldspar phenocryst, similar to those of the rocks above described, the feldspars in the groundmass are also alike. The groundmass is composed chiefly of plagioclase (nearly pure albite) and magnetite; other minerals are present only in infinitely small quantities. The relative abundance of the two chief constituents is varying, generally the magnetite appears to make up 30 per cent of the volume of the groundmass. It occurs sometimes in single crystals or crystal-aggregates with a diameter of about 0,1 mm, such grains often cohere for rather extensive areas. The bigger groundmass-feldspars are then in the centre free from inclusions of magnetite; compared to the smaller ones the magnetite is more equally distributed. When rather small, the crystals often concentrate and compose a kind of matrix for the feldspars; thus the slide appears as a black bottom with rudely rectangular white areas. See fig. 19 and p. 36. But the limits between the feldspars and this magnetite matrix are jagged, being determined by the crystal faces of the ore mineral. Magnetite crystals enclosed in

[1] On a map published in the official document Riksdagsproposition n:r 50, 1910, the name »Syväjärvi malmfält» (Syväjärvi ore field) has been used for the hematite ores north of lake Syväjärvi.

the feldspars are often seen, especially in rows parallel to the longer axis of the latter. Besides there are seen single grains of titanite, occasionally also small apatite grains, crystals of zircon or a little chlorite.

The nodules are as a rule very well defined; the magnetite of the groundmass sometimes gathers round them, and they are thus bordered by a coherent ring of magnetite crystals. They are only seldom »embryonal». They consist chiefly of feldspar in somewhat elongated individuals with a length of 0,2 to 1 mm. It is plagioclase without perthitic intergrowths and is finely »striped», sometimes more broadly lamellated in the peripheric parts. The optical properties indicate that it must be almost pure albite, which is also verified by analysis No. XII. Magnetite occurs partly in small crystals, enclosed in feldspar

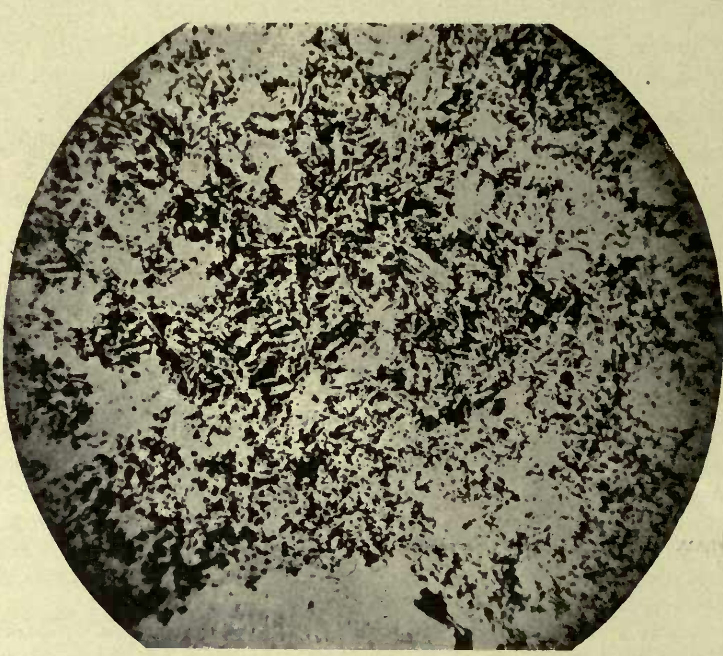

Fig. 19. Magnetite-syenite-porphyry, south of Nokutusjärvi. Ord. light. Magn. 35 times. White is albite, the black magnetite is squeezed in between the albite individuals.

or titanite, partly in bigger and more irregular lumps. Titanite is rather sparingly present, being allotriomorphic in the compact nodules. It is often plainly pleochroic with pale, somewhat reddish colours. Calcite occurs in irregular grains, sometimes having probably replaced feldspar, but mostly filling cavities. Now and then there are seen small grains of orthite.

The microscopic characters of the schlieric mixture of dark and pink-coloured rock is shown by the examination of a slide taken from one about 2 cm wide schliere of dark gray rock without any macroscopically visible nodules. The slide shows the following peculiarities. Single small albite phenocrysts are lying in a groundmass of feldspar and magnetite, the latter constituting more than 20 per cent of the volume. The feldspar shows »striped» lamination and is probably albite, it occurs in list-shaped individuals. By their parallel arran-

gement a trachytoidal flow-structure is formed, bending around the phenocrysts and the small nodules. The magnetite occurs in small crystals almost equally distributed in the feldspar mass. The size of the feldspar is different at different distances from the borders of the schliere, varying from less than 0,05 mm in the middle to 0,1 mm at the borders, where the dark rock grades into the pinkish variety with only a small amount of magnetite. This transition is now quite sudden, now more continuous. The more salic phase is coarse, its feldspar reaching a size of 0,1 to 0,3 mm, and shows no distinct flow-structure. It contains abundant apatite in thick prisms, about 0,1 mm in length, they have a rather good idiomorphism and include crystals of magnetite. »Embryonal»

Fig. 20. Magnetite-syenite-porphyry, south of Nokutusjärvi (same slide as fig. 19). Nic. +. Magn. 35 times. A typical compact nodule of striped albite, surrounded by the groundmass of albite and magnetite.

nodules occur in both types, they consist of feldspar, magnetite, titanite, apatite and calcite and are much elongated in the direction of the trachytoidal structure.

Rocks of the »Syväjärvi ore field». The predominant dark gray rocks contain feldspar phenocrysts varying in quantity and in size. They sometimes constitute more than half the volume of the rock, sometimes they occur very sparingly. Their length varies from less than 1 mm to more than 1 cm; as a rule they are relatively thickly tabular parallel to (010), showing mostly rectangular sections. The degree of idiomorphism varies of course with the size of grain of the groundmass. They are polysynthetically twinned according to the albite law, generally with broad lamellæ, but sometimes »striped»; twinning according to the Carlsbad law also occurs; broad lamellæ of the pericline type are seen, but very sparingly. The Roc-tourné type is also represented. As primary inclusions there occur single small crystals of zircon and magnetite, the

latter often arranged in rows parallel to the albite lamellæ; small plates of biotite are also seen. Muscovite (paragonite?) in the shape of small flakes is abundant, it is most decidedly an alteration product.

The groundmass consists of feldspar and magnetite. The former is in the main points similar to the one of the rocks south of Nokutusjärvi; trachytoidal structure winding about the phenocrysts is sometimes seen. The quantity of the magnetite is varying; on an average it is scarcely greater than in the above described rocks in this zone, i. e. 20 to 30 per cent of the volume. The local development of numerous large feldspar phenocrysts has naturally caused an increase of the magnetite percentage in the groundmass. Its distribution is rather irregular, it is most abundant in turning-in corners of the feldspar phenocrysts

Fig. 21. Magnetite-syenite-porphyry, »ore field of Syväjärvi». Ord. light. Magn. 14 times. The groundmass is in spots made up entirely of magnetite.

where it has evidently concentrated during the movements of the molten magma. See fig. 21. It generally seems to occur in somewhat smaller individuals than in the rocks south of Nokutusjärvi. This fact favours the development of the structural type represented even among them, which is characterized by the tendency to an idiomorphic development of the groundmass feldspars and by their lying in a matrix of aggregated magnetite crystals. But it also happens that the latter are equally distributed in the former or occur as rows of inclusions in the same way as in the phenocrysts. These inclusions are probably lying in planes parallel to (010). The magnetite is partly concentrated in lumps with a diameter of some tenths of a millimeter. Beside these minerals there only occur biotite in small quantities, titanite, zircon and apatite.

The nodules are now »embryonal», now very well defined, generally rounded, they consist chiefly of feldspar, broadly laminated or »striped», and magne-

tite occurring in isolated crystals enclosed in the feldspar or in angular lumps. Plates of biotite are rather common as well as titanite. Calcite is sometimes very abundant. It often occurs together with the rutile-like mineral, this association being common also in other rocks makes it rather probable that the latter and part of the calcite are alteration products of titanite.

The pink rocks. A slide from a small schliere with a rather sharp contact towards the dark gray rock shows the following. Feldspar is by far the predominant constituent, it occurs in small grains reaching a size of only 0,02 to 0,05 mm; they are smaller than those of the adjacent dark rock and more isometric. Beside the feldspar there occur scattered grains of apatite and magnetite. A more widely distributed type is more coarse-grained and consists chiefly of isometric grains of feldspar reaching a diameter of 0,1 to 0,4 mm. The feldspar is polysynthetically twinned, with broad lamellæ or »striped». Quartz occurs in a considerable quantity and seems to be of primary origin. Apatite is rather rare, occurring in irregular prismatic grains reaching a size of up to 0,3 mm. Magnetite and zircon occur sparingly in small individuals. Calcite impregnates the whole bulk of the rock.

Chemical characters.

An analysis of a dark gray rock with nodules consisting chiefly of feldspar, from the area south of Nokutusjärvi, has been made by R. MAUZELIUS and shows the following result:

	XII	XII a
SiO_2	45,32	750
Al_2O_3	13,09	128
Fe_2O_3	21,74	135
FeO	7,12	99
MnO	0,04	1
MgO	0,18	5
CaO	2,19	39
BaO	trace	
Na_2O	7,51	121
K_2O	0,17	2
H_2O +	0,24	13
TiO_2	1,15	14
P_2O_5	0,32	2
CO_2	1,26	29
S	0.02	
Sum	100,35	
H_2O —	0,08	

No. XII a gives the molecular proportions of analysis No. XII, multipl. by 1000.

At the calculation of the norm no account is made of the calcite, but that has no influence on the place in the system given to the analysis. It is therefore evidently of no consequence for the classification of the rock whether the mineral is considered as a primary constituent, as a product of the alteration of the feldspar or of infiltration. The second possibility is almost excluded in this analysis as such a small amount of Al_2O_3 is left after the calculation of the alkali feldspars.

American system.

	XII.	Norm.		
Orthoclase . . .	$K_2O . Al_2O_3 . 6\ SiO_2$	1,12	F 66,29	Sal 66,29
Albite	$Na_2O . Al_2O_3 . 6\ SiO_2$	63,77		
Anorthite . . .	$CaO . Al_2O_3 . 2\ SiO_2$	1,40		
Magnetite . . .	$FeO . Fe_2O_3$	19,95	M 29,92	Fem 30,54
Hematite . . .	Fe_2O_3	7,84		
Ilmenite	$FeO . TiO_2$	2,13		
Apatite	$3\ CaO . P_2O_5$	0,62	A 0,62	
				Sum 96,83
Calcite	$CaO . CO_2$	2,80		

Remainder: $H_2O = 0{,}24$ and the following molecules: $SiO_2 = 2$, $MgO = 5$ and $CO_2 = 1$ the allotment of which to minerals molecules seems to be unnecessary. .

Class 2 Dosalane, Subclass 1 Dosalone, Order 5 Germanare, Rang 1 Umptekase, Subrang 5.

From the above calculations it will be seen still more plainly than from the microscopic examination that the group of rocks here called »magnetite-syenitic» is a very peculiar type with regard to its chemical composition.

Among the feldspars the strong predominance of the albite over the orthoclase is especially striking, it is much more pronounced than in any other analysis from this region. The low percentage of anorthite is also very noteworthy, especially when considering the rather femic character of the rock. It is also remarkable as the plagioclases just in the districts around Nokutusjärvi very beautifully show the »striped» lamination which no doubt may be regarded as a characteristic feature of pure albite.

The nature of the dark constituents is quite as peculiar and of a very great interest concerning the question of the geological nature and relationship of the great ore masses of the region.

Analysis No. XII fills a gap in the american system and the writer herewith begs to propose that this subrang should be called *Kirunose* after the town of Kiruna.

The calculation of the mode, or the actual mineralogical composition of the rock, offers some difficulties.

The mode of occurrence of the titanium is unknown, it is not very probable that it should occur exclusively as ilmenite or as titaniferous magnetite, especially as titanite is a common constituent of the nodules. The silica available to form titanite is, however, a very small quantity and we have therefore here attributed the titanium to the magnetite group.

The microscopic examination shows no individuals with the shape common to the rock-forming hematite, the high percentage of iron oxide is therefore probably of a secondary development, the magnetite being in part altered to martite.

The calculation of the original composition of the rock thus gives the following result, the calcite is taken into account in *a* but not in *b*.

	a	*b*
Orthoclase	1,1	1,1
Albite	63,8	65,7
Anorthite	1,4	1,1
Magnetite	28,7	29,6
TiO_2 in »	1,0	1,0
Apatite	0,6	0,6
Calcite	2,8	—
Rest	0,6	0,6
	100,0	100.0

About $^2/_3$ of the rock are thus made up of albite and about $^1/_3$ of magnetite.

In the system of graphic representation used by MICHEL-LÉVY and BRÖGGER, the rock has a very strange appearance, especially due to the predominance of Na_2O and Fe_2O_3 + FeO.

Apatite veins.

In the zone south of Nokutusjärvi veins of finely crystalline, white or gray apatite occur here and there; they are up to 5 cm thick. Their borders are as a rule straight and well defined, and angular rock fragments occur enclosed in the apatite mass. The rock immediately adjacent to the contact is often red, instead of dark gray.

Near the south end of the series of outcrops of this zone, for at least some square meters, the rock is interwoven with small veins and strings of apatite to such a degree that it is quite brecciated. The veins are generally only a few mm wide. The rock fragments are often angular, with well defined outlines towards the apatite, but sometimes no distinct limit is to be seen. The apatite also occurs in patches in the rock. It is finely crystalline and of a white or pinkish colour. Magnetite occurs associated with it in dense lumps reaching a diameter of some mm, calcite occurs very often too. The appearance of the rock is very varying, it is now gray in different shades, now reddish. Some fragments contain

magnetite nodules. The gray pieces are often red in the immediate neighbourhood of the borders,

The larger apatite veins show the following characters under the microscope. The apatite occurs in thick prisms with an average length of 0,5 to 0,7 mm, it often contains small plates of red hematite, principally on cleavage cracks. Plagioclase feldspar (presumably albite) occur in a considerable quantity, in individuals reaching up to 1 mm in diameter. It now shows a tendency to idiomorphism, and now forms a mesostasis, ophitically larded with apatite prisms and grains. In both cases it happens that such inclusions are optically orientated in the same way in relation to each other and to the individuals surrounding the feldspar, the phenomenon thus getting the character of a granophyric intergrowth. This structure denotes that the crystallization of the two minerals was simultaneous. Quartz occurs in about the same quantity as the feldspar and in almost the same manner, but shows no tendency to idiomorphic development. Titanite is rare and occurs in irregular grains altering to brown ochre. Calcite occurs in a considerable quantity, in grains and strings between the apatite prisms; its mode of occurrence renders it impossible to determine whether it is a primary constituent or may be a product of the weathering of the apatite. Orthite also occurs filling fissures and spaces between the other minerals. The contact with the porphyry has been examined under the microscope in one case only and then showed to be very well defined. The rock is to a width of 1 cm almost free from magnetite, but rich in apatite in small grains and also in red pigment.

The rock interwoven with small veins and strings consisting chiefly of apatite, comprehends phases rich in magnetite as well as more normal porphyries (but always without dark silicates). The magnetite is often concentrated in lumps or forms nodules together with »striped» albite feldspar, which partly forms a ring around the ore mineral, partly occurs within the same. Some nodules are »embryonal» and consist of a mixture of magnetite and albite with a structure similar to the one described p. 37, these patches grade into the normal groundmass. The veins consist of apatite, magnetite, feldspar and calcite, and of biotite, quartz and a brown mineral, probably an alteration product of titanite, in very subordinate quantities.

The brown mineral is the same as described p. 31 and is probably rutile, though its optical properties are difficult to determine exactly on account of the covering of brown ochre. It occurs in irregular grains and ribs.

The apatite occurs in thick prisms having a length of some tenths of a millimeter; the magnetite is generally concentrated in jagged lumps, evidently aggregates of crystals. The feldspar is probably albite, it is broadly lamellated or »striped» and younger than the before mentioned minerals. The calcite mostly occurs in concentrations all by itself, without any apatite, it includes magnetite and albite, the latter showing sharp angles.

The limits between the veins and the rock groundmass are not very distinct, especially as the feldspars occuring in the former are partly quite similar to those of the latter. Some veins almost have the character of elongated lenses. They show transitions to the nodules and are probably of an origin similar to theirs.

Valkeasiipivaara.

Along the exposed conglomerate area there extends an about 1300 meters long and 40—200 meters wide band of outcrops of syenite-porphyry. The rocks are fine-grained or dense, with a few small feldspar phenocrysts, the colour is reddish gray or gray. A very pronounced jointing system is sometimes seen, running almost parallel to the border towards the conglomerate and dipping at about 60° to the east- southeast, it divides the rock into slabs with a thickness of some cm. The contact with the conglomerate, which in one place has been exposed by digging, is quite sharply defined. The porphyry is close to the latter quite massive and unaltered, but somewhat inhomogeneous, consisting of coarse lenses reaching a length of some cm, enclosed in a somewhat more fine-grained matrix.

One phase, somewhat different from the others, is exposed in a small waterfall at the eastern border of the exposed area, near the path from Kiruna to Kurravaara, and in the adjacent outcrops up to the conglomerate. The first-mentioned outcrop is described by FREDHOLM [12] who believed it to consist of a sedimentary rock belonging to the conglomerate. The rock is dense, pure gray in colour, with several up to a few cm long, often angular spots of a blackish gray colour. It is is accordingly rather similar to a tuff and this impression is still more heightened by the jointing which resembles the above described one.

The strike of the jointing is always almost coincident with the direction of movement of the pleistocene ice sheet in this region. The result of this fact has been a formation of low rocks, much elongated in this direction.

The microscopic examination of the typical porphyry shows a few small plagioclase phenocrysts in a groundmass of feldspar and hornblende, and some magnetite and biotite. The phenocrysts are to a great extent altered to epidote. The feldspar of the groundmass is partly striated and appears in elongated grains, scarcely 0,1 mm in length. The bluish green hornblende forms small

grains or uneven columns, some of them reaching a length of 0,3 to 0,4 mm.

A slide of the rock some dm away from the above mentioned contact with the conglomerate shows the outlines between the coarse lenses and the surrounding matrix not to be very sharp. Both contain badly idiomorphic feldspar phenocrysts reaching a length of some mm. The groundmass is chiefly made up of »striped» plagioclase in somewhat elongated grains, in the coarser phase reaching a size of 0,10 to 0,25 mm, in the fine-grained one a size of less than 0,1 mm. In the latter there are also seen nodule-like aggregates of rather large feldspars. Magnetite occurs in the former in the shape of crystals with a diameter of some tenths of a millimeter, in the latter in much smaller grains. Biotite is most common in the fine-grained phase, which also contains some titanite and apatite. This phase shows fluidal structure bending around the coarser lenses. The rock is probably an igneous flow-breccia.

The tuff-like rock described by FREDHOLM consists chiefly of feldspar and quartz, both in very irregular grains having a size of less than 0,1 mm. The feldspar is predominant, it is as a rule distinctly striated. Isolated rather large quartz grains or elongated (sometimes up to some mm long) aggregates of such grains are seen here and there. Magnetite in small crystals is equally distributed and makes up at least 5 per cent of the rock. Titanite and hornblende occur in small quantities. The dark »spots» are rather well defined, their outlines often being marked by a granular quartz mass. They are now angular, now sinuous and consist of magnetite-syenite-porphyry, the magnetite making up 15 to 30 per cent of the volume. The rest is »striped» plagioclase, in some fragments occurring in elongated individuals up to 0,3 mm in length, in others in sphærulitic groups. Besides there occur titanite and some chlorite. Nodules are seen here and there; they consist of the minerals just mentioned. The nature of this fragmental rock is uncertain, the writer being, however, most inclined to regard it as having originated in the same way as the one described immediately above. The quartz is probably of secondary origin.

Hopukka and Välivaara.

Exposures and kinds of rock.

On the Hopukka Mountain, there are several outcrops and some prospecting diggings, but the exposures are not numerous enough to render possible a quite certain explanation of the mutual relations of the partly very peculiar rocks. Rocks belonging to the syenitic group occupy the greater part of the mountain, at the southeastern side there occur some quartz-porphyry, and the hematite zone of the Nokutusvaara ore field, and still further east, the schistose syenite-porphyry of the Hauki complex.

Mount Välivaara, which is situated northeast of Hopukka and is separated from the latter by a narrow marsh, reaches about the same height. On its northwestern and northern sides there are outcrops of the Kurravaara conglomerate, on the east one there occur outcrops of the quartz-porphyry and of the Hauki complex. Between these there are seen a few exposures of rocks which are very probably a continuation of the syenitic group which we have followed from Kiirunavaara.

All exposures of syenitic rocks are indicated on the accompanying sketch map (fig. 22), on a scale of 1:10000.

Petrographic characters.

No. 1. Small outcrops of a very fine-grained reddish gray rock with scattered grains of hematite and small quartz nodules. The rock has not been examined under the microscope, as it is evidently very similar to the one of the group of exposures No. 7.

No. 2. In the western part of this outcrop the rock is very fine-grained and dark gray, about one-third of it consisting of nodules of

yellowish white feldspar. These nodules are much elongated and reach a length of more than 1 cm. Lower down in the same outcrop the rock contains smaller, more isometric nodules. East of these phases — but still in the same, only some meters long outcrop — there is a pinkish feldspar rock, connected with the above mentioned ones by a rapid transition.

Under the microscope the first mentioned rock appears to be a typical magnetite-syenite-porphyry with feldspar nodules. It contains a few plagioclase phenocrysts, probably albite, often dark on account of the finely distributed magnetite which they contain. Rather big lumps of this mineral are also sometimes enclosed. The groundmass consists of feldspar and magnetite, the latter making up about 25 per cent of the volume. The feldspar occurs in broadly rectangular sections reaching a length of about 0,1 mm, it shows »striped» lamination and accordingly seems to be albite. The magnetite crystals are small compared to those of the feldspar, they are equally distributed in the latter. The nodules are rather well defined and consist chiefly of plagioclase and of quartz and cal-

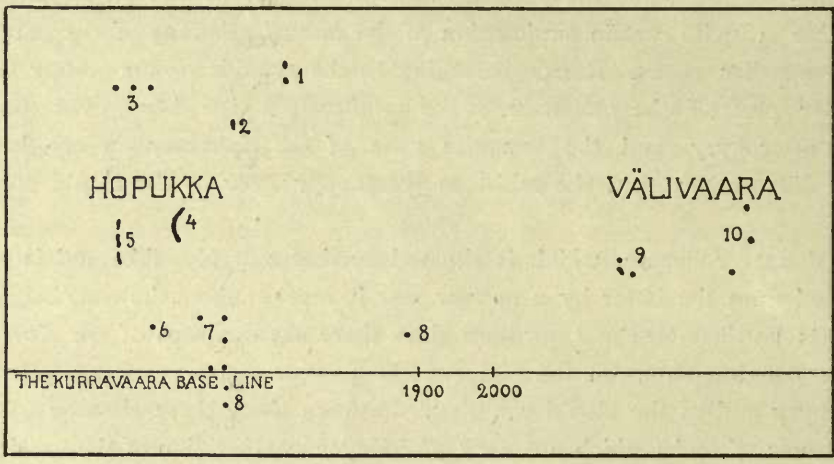

Fig. 22. Map showing distribution of outcrops of syenite-porphyry, Hopukka and Välivaara. Scale 1:10000.

cite. The plagioclase is broadly lamellated or »striped» and is presumable albite, it occurs in individuals reaching a size of 0,3 to 0,5 mm and is often idiomorphic towards the quartz. The latter forms irregular grains of varying dimensions. The calcite forms small strings and lumps in the nodules as well as outside them.

The other variety differs from the just described one by containing somewhat less magnetite and by the nodules being much smaller and partly »embryonal».

The pink-coloured rock contains plagioclase phenocrysts just as the dark ones, in a groundmass made up chiefly of »striped» albite in somewhat elongated, sinuous individuals reaching a length of 0,1 to 0,2 mm. Magnetite occurs in scattered small crystals, quartz is present here and there in isometric grains. There are also a few small grains resembling rutile. A yellowish pigment occurs now and then between the feldspars. The nodules are isometric and quite

small, they are similar to those of the above described variety, but contain a little more quartz.

These rocks are accordingly a continuation of the zone of magnetite-syenitic composition, which has already been met with south of Nokutusjärvi and in the »ore field of Syväjärvi.»

No. 3. In these outcrops the rock is blackish gray, dense, interwoven with strings and lenses of calcite containing scattered grains of pyrite. It is very similar to a part of No. 4.

No. 4 is an almost vertical precipice attaining a height of up to about 6 meters. The rock of the western half contains small red feldspar phenocrysts in rectangular sections in a dense, blackish gray groundmass. Small patches of ferruginous carbonate also occur. Near the middle of the slope it is breccia-like, interwoven with countless veinlets and patches of a lighter rock. There also occurs an almost vertical, some dm wide band of a somewhat shistose gray rock. East of it the aspect of the rock is gradually changed and it passes into a quite as fine-grained, not very hard, but extremely tough rock, the colour af which is dull black on a fresh surface, on a weathered one bluish black. It is very rich in nodules mostly consisting of quartz, often with drusy cavities, and of calcite with a small percentage of carbonate of iron. Grains of chalcopyrite are also present. Farthest east the rock it tuff-like, the dark rock forming sinuous boulders in a quantitatively very subordinate matrix of a dingy white colour, which also penetrates the boulders in the shape of small veins.

The direction of strike seems to be almost at right angles to the extension of the precipice but is very indistinct.

A slide of the rock at the western end of the slope shows the following: The feldspar phenocrysts which reach a length of up to some mm are plagioclase with »striped» lamination, and sometimes also with twinning according to the Carlsbad law. They are partly rather well idiomorphic and enclose rather sparingly plates of biotite and grains of partly altered titanite. The groundmass consists almost exclusively of feldspar and magnetite, the latter occurring in such a great quantity that the rock must be characterized as a magnetite-syenitic one. The feldspar occurs in thin lists reaching a length of scarcely 0,1 mm or in more isometric grains; the outlines between the different individuals are disguised by the high percentage of magnetite which also makes the determination of the optical properties difficult. Lamination appears, however, sometimes very distinctly. The mode of occurrence of the magnetite is very striking. It forms small crystals generally reaching a length of scarcely 0,01 mm, which are arranged in rows now parallel to one another, now, and that is more often the case, divergent. (Fig. 23). These bunches of rows of magnetite crystals resemble those described p. 31 which are composed of magnetite and hornblende, but they are better developed; they are also very similar to the skeleton structures in the ore

of Kiirunavaara which by this analogy get an unexpected explanation (See p. 95 and fig. 31—33). Flow-structure is sometimes seen, (fig. 24). The phenocrysts are often immediately surrounded by a zone in which the structure is of the usual kind, though it is much more fine-grained. In some phenocrysts such rows are enclosed in the most peripheric parts. The writer has not found any crystallographic regularity in this skeleton structure. Beside these minerals there occur single plates of biotite and crystals of ferruginous carbonate. Small nodules (less than 1 mm in length) are rather abundant, they consist of plagioclase, calcite and quartz, the latter being predominant. They are partly very »embryonal», the magnetite rows of the groundmass continuing in the feldspar of the nodules, probably also in the quartz.

The brecciated rock in the middle of the slope is under the microscope seen to consist of fragments of a rock similar to the above mentioned one, but extremely rich in magnetite, embedded in a salic matrix. The latter contains

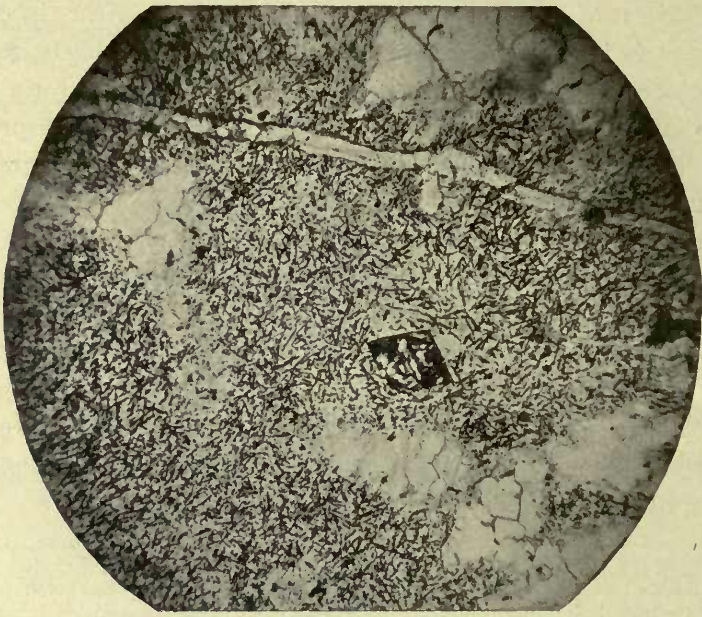

Fig. 23. Rock from the middle of loc. 4, Hopukka. Ord. light. Magn. 35 times. Skeletons of magnetite in the groundmass. White areas are quartz nodules, the crystal near the centre is a ferruginous carbonate.

plagioclase phenocrysts; its groundmass consists of feldspar in sinuous grains, having a diameter of less than 0.1 mm, and of quartz, which in some places, especially in small spaces between fragments, makes up nearly the whole volume; biotite in small plates is present, but only seldom. Embryonal nodules occur, consisting of quartz, albite and calcite. The rock in the fragments is rather variable but not more than allows the different fragments to remain in situ and seem never to have been intermixed with one another. It contains a few plagioclase phenocrysts, generally having no other inclusions than a few small plates of biotite and being somewhat corroded. The groundmass consists of feldspar, magnetite and sometimes a little biotite. The magnetite occurs in very varying

quantities, sometimes it constitutes only about 20 per cent of the volume, but occasionally much more, there even occur fragments consisting almost exclusively of this mineral. When occurring in a relatively small quantity it is often finely distributed as a dark pigment, otherwise it is often more or less distinctly arranged in rows of crystals in the same manner as has already been described. The feldspar is probably polysynthetically twinned, but the great quantity of magnetite renders the determination of its optical properties rather difficult. It occurs in very narrow lists, less than 0,1 mm in length and sometimes sphærulitically grouped. In some cases the feldspar mass has the appearance of devitrified volcanic glass.

The size of the fragments varies from several cm to fractions of 1 mm, they are now sinuous or rounded, now angular, some part often being defined

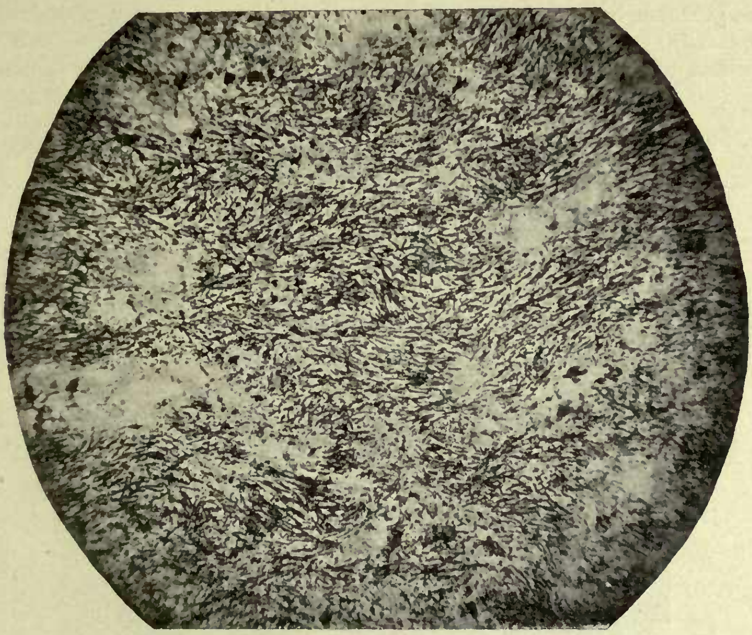

Fig. 24. From the same slide as fig. 23. Ord. light. Magn. 35 times. Shows the fluidal arrangement of the magnetite skeletons.

by concave lines, (see fig. 25) as is common with glassy fragments. The matrix also intrudes the fragments in the shape of small veinlets.

The rock accordingly consists of a rock extremely rich in magnetite, probably at least in part originally solidified as glass, in a matrix of an altogether different composition and probably highly silicified.

The black rock further east and the fragments in the agglomeratic phase occupying the easternmost part are rather similar to the above described ones rich in magnetite, but are especially rich in biotite, the magnetite percentage, to judge from the material collected by the writer, being rather variable and on an average much lower than in the latter. The matrix of the agglomeratic phase consists chiefly of quartz in irregularly polygonal grains having a diameter of about 0,1 mm, of biotite in considerable quantities, scattered crystals of magne-

tite and fibrous rays of tourmaline reaching a size of about 0,15 mm in diameter. The pleochroism is: O = brownish green; E = pinkish; absorption O > E. There also occur single crystals or irregular grains of calcite. The biotite is especially concentrated along the outlines of the fragments, probably lying partly in them.

No. 5 is a row of outcrops of dark gray or reddish gray rocks, sometimes with quartz nodules, similar to the rock in the eastern part of the above mentioned one.

The microscopic examination of a slide shows a mass of small, elongated feldspars (scarcely reaching a length of 0,1 mm); the low refraction and birefringence indicate potash-feldspar or sodamicrocline. Of dark minerals there are present greenish brown biotite and magnetite. Calcite is very abundant, occurring especially in rounded spots together with hematite, sometimes also together with prisms of tourmaline reaching a length of some tenths of a millimeter.

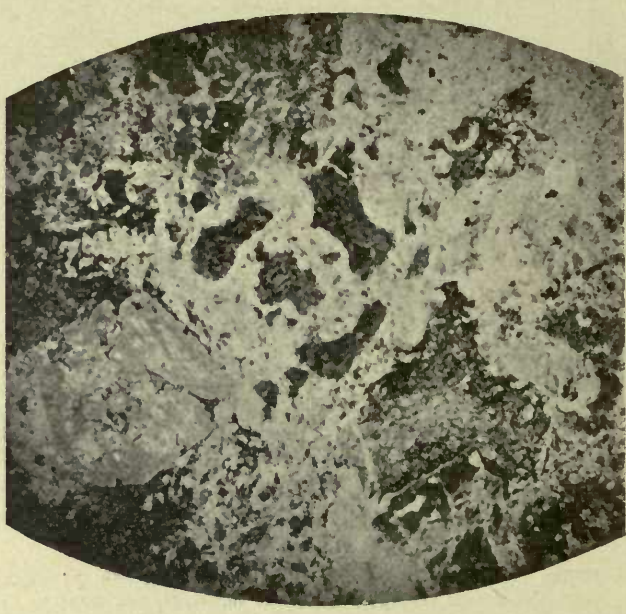

Fig. 25. Brecciated rock, loc. 4, Hopukka. Ord. light. Magn. 14 times. Shows fragments of a highly magnetite-bearing rock with some large feldspar phenocrysts, in a salic, silicified matrix. Note the black magnetite areas in some fragments!

In the most south-easterly outcrop of this group there occurs a grayish white, massive quartzite, into which the dark igneous rock changes. The microscopic examination shows patches of feldspar rock rich in biotite and apatite, embedded in a mass of quartz grains of various shapes and sizes, generally irregular and fringed. An almost total silicification of a porphyry is evidently at hand here.

Similar to the porphyries of No. 5 is a small exposure, located in the continuation of this row, but some 40 meters on the other side of the base line.

No. 6. Very fine-grained, dark gray rock, occasionally with a reddish tinge.

Under the microscope it is seen to consist chiefly of feldspar in lists reaching a length of about 0,1 to 0,2 mm, sometimes radially arranged. The refraction as well as the birefringence are low and it is very finely cross-twinned. It is more similar to anorthoclase than to microcline. Besides, the rock contains rather much magnetite in small crystal aggregates, and biotite. Secondary quartz is rather rare.

Only some 20 meters east of this exposure there occurs quartz-porphyry.

No. 7. Fine-grained rock of a dark gray or grayish red colour, with feldspar phenocrysts reaching a length of a few mm, and much hematite, equally distributed.

A slide shows the following. The feldspar phenocryst are little idiomorphic and extensively altered to muscovite. The groundmass consists chiefly of feldspar containing some red pigment, at a strong magnification (450-fold) an extremely fine striation is visible here and there. The individuals reach a size of 0,2 to 0,4 mm in diameter and are broadly rectangular, the structure differs from the one common to our rocks in this, that the outlines between the different individuals are rather uncomplicated and often quite straight. Squeezed in between them there occur grains of hematite, quartz and limpid, broadly lamellated plagioclase. The quartz shows no tendency to idiomorphic development.

No. 8. The rock in these exposures is a rather homogeneous type, characterized by small, red, rectangular feldspar phenocrysts and abundant nodules of quartz, in a dense groundmass of a reddish gray or reddish brown colour. In the most northerly exposure the nodules are not as numerous as in the other ones, but otherwise the rocks of the different places resemble one another. The nodules often contain small plates of hematite, as is often seen in the vesicles of recent lava rocks. Flow structure is sometimes developed by the arrangement of the nodules.

The microscopic examination shows the phenocrysts to be of two different kinds. The most common ones are rather well idiomorphic, but almost totally altered to an aggregate of small muscovite plates. Polysynthetical twinning occurs now and then, but it is impossible to ascertain whether the areas showing it are perthitic intergrowths or not. Inclusions of hematite are occasionally seen. The other type is similar to the above described one in shape, it is unaltered, broadly lamellated plagioclase with low extinction angles in sections cut at right angles to (010). These phenocrysts contain inclusions of hematite of the same quantity as in the surrounding groundmass. A big crystal of this type has been observed enclosed in one of the other type.

The groundmass consists of feldspar and hematite. The former sometimes shows lamination and occurs in short rectangular individuals, generally less than 0,1 mm in length, between them there is red pigment. Sphærulitic arrangement

sometimes occurs, and the individuals are then more elongated. The hematite occurs in considerable quantities, as a rule in the shape of angular lumps reaching a size of 0,1 to 0,8 mm in diameter.

The nodules consist of quartz in irregular grains; hematite is inserted from the walls into the quartzes.

In the most easterly outcrops these rocks are cut by dikes of a dense, heterogeneous rock of a gray or almost black colour, partly rich in hematite. The dikes have well defined borders but vary rapidly in width, they enclose numerous fragments of the wall rock.

The microscopic examination shows the constituents of the dike rock to be quartz, plagioclase, tourmaline, hematite, muscovite and apatite. The quartz is generally the predominant mineral, and occurs in grains of varying dimensions, generally scarcely less than 0,1 mm in size. In some parts of the slide the feldspar predominates altogether, it occurs especially in somewhat elongated individuals reaching a length of 0,2 to 0,3 mm, they are idiomorphic towards the quartz and their outlines towards one another are rather uncomplicated. It is broadly lamellated according to the albite law, sometimes also with pericline lamellæ. Other feldspars are allotriomorphic and enclose grains of quartz. The tourmaline makes up about 25 per cent of the rock and is especially accumulated around the rock fragments. It occurs in prisms without terminal faces, reaching a length of 0,2 to 0.4 mm. The pleochroism is: O = bluish green; E = pinkish; absorption $O > E$. The hematite occurs in acicular individuals (or aggregates of individuals). The muscovite in small flakes is a minor constituent, and the apatite is of even less importance.

With its high percentage of tourmaline and quartz the dike rock is rather similar to the matrix of the brecciated phases of No. 4. It has too distinct pneumatolytic features to be a normal igneous rock, but it cannot be a product of sublimation or crystallization from an aqueous solution of normal temperature. It has probably been deposited from a hot solution rich in silica, boron and fluorine.

No. 9. A large outcrop on the southern slope of Välivaara, consisting of a porphyry with numerous fragments, generally rounded and reaching a size of 1 or a few dm. The main rock is reddish gray with small feldspar phenocrysts in a fine-grained groundmass. The fragments are partly homogeneous, but sometimes contain small light nodules.

The microscopic examination of the main rock shows the following. The rock is rich in partly corroded feldspar phenocrysts reaching a size of 1 or a few mm. They are much altered to sericite. The refraction is considerably lower than that of the Canada balsam. The groundmass consists chiefly of unaltered feldspars in elongated crystals, hardly 0,1 mm long and often trachytoidally arranged. The refraction is similar to that of the phenocrysts. The birefringence is low. On a whole, the feldspar of this rock is very similar to the anorthoclase or microcline of some Hopukka porphyries. Besides, there are seen magnetite in large crystals and some zircon. There are also angular pat-

ches, consisting of muscovite and magnetite in striped alternation, they are probably pseudomorphoses. The small nodules consist of quartz and apatite. One fragment has phenocrysts, reaching a length of a few mm. They are badly idiomorphic and broadly lamellated according to the albite — sometimes also to the pericline — law, the refraction is almost similar to that of the Canada balsam. The groundmass consists mostly of »striped» plagioclase in elongated individuals reaching a length of 0,15 to 0,20 mm, with fringed outlines. Magnetite in small crystals is rather common; skeleton individuals of titanite occur both in the phenocrysts and in the groundmass, apatite is not uncommon. Calcite impregnates the whole mass, and streaks and patches of polygonal quartz grains are seen here and there.

One fragment appears to be even-granular, almost exclusively made up of isometric feldspars reaching some tenths of a millimeter in diameter. They are generally finely irregularly cross-twinned, a few show only albite lamination, and some appear to be homogeneous. Sericite occurs in a small quantity as a product of alteration. Single magnetite crystals occur, they reach some tenths of a millimeter in diameter and are well idiomorphic.

Another fragment consists chiefly of feldspar, showing sharply rectangular sections varying in length from 0,1 to 1 mm. They are much altered to scaly sericite, which renders the determination of their optical properties difficult. The birefringence is low, and in some of the larger ones an extremely fine lamination has been observed, but it is doubtful whether it ought to be regarded as microcline, anorthoclase (soda-microcline) or perhaps albite. The last mentioned eventuality is, however, not very probable. Between these feldspars there is seen a quantitatively subordinate groundmass, made very brown by pigment and rich in magnetite. It is birefringent and probably consists of feldspar. The very small magnetite crystals are arranged in skeleton rows more straight and regular than those in the groundmass of the Hopukka rocks described p. 75. The rock contains single, compact nodules, consisting of finely and irregularly cross-twinned feldspar, magnetite, hematite and muscovite (talc ?).

Some other fragments are similar to the last described one, but their feldspars are broader, and the magnetite occurs in single big crystals and not as skeletons. With the exception of the first described one, all the fragments are accordingly more or less closely related to the matrix rock.

No. 10. All these small outcrops consist of a reddish gray or brownish gray porphyry, which in the most easterly exposure includes numerous rounded fragments of a dark gray rock.

The examination of a slide of this outcrop shows the main rock to be very similar to the matrix rock of No. 9. It is rich in feldspar phenocrysts with irregular outlines and having a diameter of some mm; the usual alteration to scaly sericite has gone rather far, but distinct cross-twinning is nevertheless sometimes seen. The groundmass consists almost exclusively of elongated feldspars of varying size, generally scarcely less than 0,1 mm in diameter. Magnetite and muscovite (talc?) occur in a striped lamination and form angular patches. A pseudomorphose is evidently at hand, but it is uncertain which has been the original mineral (biotite?) In other cases the magnetite occurs very sparingly. The fragments are of the already described type with a very subordinate groundmass with magnetite skeletons. Strings of quartz, in part hematite-bearing, interweave the main rock as well as the fragments.

The most interesting feature of the rocks of Välivaara is of course the occurrence of types with very volcanic characters, such as are especially represented among the fragments. The close relation existing between the matrix and the greatest part of the fragments ought also to be emphasized.

Part of the syenitic rocks on Hopukka consequently shows strong traits of consanguinity with those already described, with regard to the nature of the feldspar, the predominance of the magnetite (or the hematite) among the dark constituents and the development of nodular structure. On Välivaara these characteristics are much less pronounced. Structurally the rocks of both mountains differ somewhat from the above described ones by having more pronounced volcanic characters. It is also worth mentioning that the nodules in some phases, especially in the rock described under No. 8, have the characters of common amygdules in a higher degree than is common with the rocks of this region. The brecciated phases have probably originated by the interweaving of the rock with veinlets of the same nature as the dikes in No. 8, and are not true tuffs. The formation of these dikes and of the strings and veinlets of quartz, hematite, calcite and some tourmaline and biotite occurring as well on Hopukka as, when also in much smaller quantities, on Välivaara, and the silicification described p. 78, seems to be contemporaneous with the fumarolic and hydrothermal action, the strong traces of which are seen in the rocks overlying the quartz-porphyry and described in connection with the Rektor and Nokutusvaara ores.

Comparison between the syenite rocks of the different localities.

We have now followed the rocks of the syenitic group from Kiirunavaara up to Välivaara, a distance of about 13 km. All this enormous mass of igneous rocks shows a marked consanguinity between its different parts, but at the same time successive changes in the chemical composition in the longitudinal direction of the region. The resemblances have in the above been pointed out several times, but these dissimilarities have not been emphasized. The latter are especially an increasing of the soda percentage at the cost of that of potash when going from Luossavaara to Hopukka and an analogous increasing of the magnetite percentage among the dark minerals, in the same direction, the latter, however, appearing even in the Luossavaara rocks. On Kiirunavaara we find microperthite to be the predominating feldspar, the same is the case on Luossavaara, but perhaps not in as high a degree, while further off, on both sides of Nokutusjärvi, the feldspar is altogether almost pure albite. But in some rocks of Hopukka we do not find the common albite, and on Välivaara there occur phases, the predominant feldspar of which seems to be anorthoclase, or perhaps even microcline. The hornblende diminishes rapidly in quantity towards the northeast of Luossavaara. On Kiirunavaara it is widely distributed together with its mother mineral, the augite, on Luossavaara the hornblende occurs in almost the same quantity, immediately south of Nokutusjärvi it is rare and is totally missing, as far as is hitherto known, on Hopukka and Välivaara. Biotite, on the other hand, gets somewhat more common, as also happens with the Kiirunavaara rock varieties more rich in magnetite. Only the rocks occurring along the Kurravaara conglomerate northwest and north of Luossavaara are in these respects rather similar to those of Kiirunavaara.

The geological mode of occurrence of these syenitic rocks cannot be determined as exactly as would be desirable on account of the large covered areas between the groups of exposures. It has already been pointed out that on Kiirunavaara the syenite and the »older» porphyries are structural phases of the same geological unit. Neither on Luossavaara nor in the exposed area between this mountain and Nokutusjärvi there can be proved any difference between the ages of the rocks of this group, but it is of course impossible to ascertain whether the two and those on Kiirunavaara belong to the same eruption. The rocks on Hopukka have more volcanic characters than the other ones and may perhaps represent several separate lava flows. From ZENZÉN'S examinations it appears that the syenite group probably runs continuously much further towards the northeast in the shape of one of the lava beds interstratified in the sedimentary rocks on the Kurravaara mountains.

The relations between the rocks along the Kurravaara conglomerate north of Luossavaara and the other rocks of syenitic composition seem to be almost impossible to determine without the aid of extensive digging in the covered area immediately east of them. No conclusions regarding the relative ages of the different rocks of the Jukkasjärvi ore-bearing region can be drawn from resemblances or dissimilarities in mineralogical composition and structure. Rocks from quite distant parts of this region may be quite identical in hand specimens and under the microscope, while in the same outcrop there are found several rather different types in a schlieric alternation, as has already been described several times.

In a following chapter the reasons for regarding these rocks as extrusives and their relations to other sedimentary and igneous rocks of the region will be more closely discussed. It is also more suitable to discuss other characteristics of the syenitic rocks in a later chapter, as for instance the nature and the geological importance of the magnetite-syenitic magma, and the origin of the nodular structure.

The Ores of Kiirunavaara and Luossavaara.

These enormous magnetite masses, of which Kiirunavaara is the greatest known continuous ore body in the whole world, occur at the border between the syenitic rocks and the quartz-porphyry.[1]

Mineralogical composition.

The ore mineral is magnetite, generally dense or very finely crystalline. It is to a small extent, chiefly in Professorn, mixed with hematite. The ore being just there uncommonly porous and somewhat infiltrated with quartz substance, the hematite is probably secondary and not of primary origin. Of primary origin are on the contrary tabular crystals of this mineral, which coat or fill fissures in the ore in several parts of the mountain (for instance Geologen and Kapten) and fine stringers or small rounded lumps which are also rather common. It is, of course, not quite impossible that some hematite occurring equally distributed in the magnetite may be of primary development.

The apatite is the most important gangue mineral both with regard to quantity and from an economical point of view. By its great quantity it rendered the use of the ore impossible until the invention of the basic process altered the situation, and it still plays a very important part. Pyroxene and hornblende are much inferior to the apatite with regard to their quantity. Their distribution is very limited. Other barren minerals are quantitatively of no importance. It is, however, worth mentioning that the sulphur percentage seldom is higher than $0{,}_{05}$, and that the TiO_2 percentage varies between $0{,}_{04}$ and $0{,}_{80}$ in Kiirunavaara, and in Luossavaara sometimes reaches as much as $1{,}_{36}$.

As the small parts with a considerable silicate percentage are not reckoned as ore, the latter may be regarded as a mixture of the two minerals magnetite and apatite in very varying proportions. The iron works are supplied with ore of the following qualities:

[1] Concerning the shape and size of the deposits, see LUNDBOHM's works, e. g. in »Iron ore resources of the world», Stockholm 1910.

A-ore with	less than 0,05	per cent of phosphorus.
B-ore[1] „	maximum 0,10	„ „ „ „
C-ore „	„ 0,30	„ „ „ „
	or „ 0,80	„ „ „ „
D-ore „	minimum 0,75 and generally not more than 2,5	„ „ „ „
F-ore[1] „	2—3	„ „ „ „
G-ore „	more than 2,5	„ „ „ „

Among the analyses included in the collection of »Järnkontoret»[2] the limits of the variations within different parts of Kiirunavaara are:

Vaktmästaren	(11 analyses)	62,02—70,02	per cent	Fe
		2,08— 0,018	„	P
Grufingeniören	(16 „)	50,15—69,80	„	Fe
		5,03— 0,025	„	P
Geologen	(9 „)	52,32—68,35	„	Fe
		4,55— 0,40	„	P
Statsrådet	(6 „)	57,67—65,53.	„	Fe
		3,14— 1,18	„	P
Landshöfdingen	(16 „)	60,92—69,45	„	Fe
		2.30— 0,047	„	P
Professorn	(16 „)	66,13—69,90	„	Fe
		1,03— 0,022	„	P

The lime varies with the phosphorus, the percentages of other oxides are usually: SiO_2 1,00—2,00; Al_2O_3 0,30—1,50; MgO 0,30—1,20; MnO 0,28—0.80; CuO trace.[3]

Physical properties.

The ore shows a rather irregular but very conspicuous jointing which makes the effect of blasting very great. A very pronounced cleavage system strikes and dips about similarly to the ore body as a whole. The ore sometimes altogether splits into small rhomboeder-like pieces.

In some places there occurs a sort of columnar structure on a very small scale, the most beautiful occurrence being found on the northeastern slope of Landshöfdingen. Ore with this structure occurs there within several dike-shaped areas each being a few meters long and about 1 meter

[1] Not produced any longer.
[2] Analyser å svenska järn- och manganmalmer, Stockholm 1906.
[3] For complete analyses see the works quoted on the precedent page.

wide. The writer has not been able to ascertain whether the areas are connected. The magnetite occurs as sticks with an irregularly angular shape in cross-section, the smallest reach a thickness of only a few mm and a length of 1 or a few cm, the measures of the greatest are respectively $1{,}5$ cm and 12 cm, all the figures being approximate. These sticks are quite parallel to one another and are arranged at right angles to the border of other ore types.

The surfaces of the sticks are often beautifully lustrous and reflecting, but I have found no crystallographic regularity. A distinct parting often appears, which on the different sticks makes the same angle, about 30°, with the longer axis.

Fig. 26. »Columnar ore», Landshöfdingen, Kiirunavaara. Nat. size.

Neighbouring sticks often have about the same size and the coarseness sometimes changes regularly in bands parallel to the border. A typical hand specimen is seen in fig. 26. It appears accordingly as if this phenomenon ought to be regarded as a peculiar, coarsely crystalline magnetite mass and not as a columnar developement of ore of the usual coarseness of grain. —

The ore is generally dense and very hard and thus offers a very strong resistance to the boring, but this has on the other hand the advantage that it is not reduced to crumbs at the transport. This is of course very important, as it is subjected to many reloadings before reaching its ultimate place of destination.

The ore is often naturally magnetic (loadstone).

Macroscopic characters.

Kiirunavaara. The ore being mostly a mixture of magnetite and apatite, a description of its macroscopic characters will chiefly treat these two minerals in their relations towards one another, the observations made on the weathered surface of the ridge being especially important. Further on we must consider the mode of occurrence of the hematite and of the pyroxene and amphibole, and lastly describe some other, less important, primary constituents and some products of alteration.

The mode of occurrence of the apatite has always been a matter of great interest to all geologists as well as miners visiting the »ore mountains». Beside the above mentioned importance of the mineral concerning the usefulness of the ore, another circumstance has, at least for some time (about 1890), contributed to its interest, viz. the expectation that the apatite itself might be mined with profit and give rise to a prosperous apatite-industry. Its mode of occurrence has moreover been of interest also to geologists with purely theoretical pursuits, and rather divergent conclusions as to the formation of the ore have been inferred from it.

LUNDBOHM was the first to study this matter more closely [41]. The first object of his work was to make out whether ore poor in phosphorus (below the Bessemer limit) was naturally present in workable quantities or might be procured by a cheap concentration process from ore more rich in apatite. When distinguishing the different ore types from one another he had in the first instance to make use of their macroscopic characters, but he could also by chemical analyses, partly also with the aid of the microscope, state the apatite percentage in each of them. A consequence of the object in view was LUNDBOHM's distinguishing only such types as are quantitatively of importance, while he was not able to pay so much attention to details which are very instructive from a theoretical point of view but are of secondary importance economically.

LUNDBOHM's classification of the ore is as follows [41].

1. Magnetite with very little phosphorus, and bright, conchoidal surfaces of fracture.

2. Magnetite containing very little phosphorus, and sometimes mixed with hematite.

3. Average phosphoric ore with compact, steel-like surfaces of fracture.

4. Highly phosphoric magnetite with apatite in nests, patches and lenses.

5. Highly phosphoric ore with finely disseminated apatite.

Beside LUNDBOHM it is chiefly STUTZER, who on the basis of his own studies has published something concerning this question. He had not time enough to make an exhaustive examination of the problem and therefore devoted himself to the varieties most rich in apatite, where he felt he would have the best chance of finding instructive features. The circumstance that STUTZER expressed a theoretical opinion on the ore after having made only a very short visit to Kiruna and did not follow up his researches there until later on, does not prevent that his works have brought the matter a good deal forward.

The close examination of the different ore varieties showed to LUNDBOHM the impossibility of producing commercial qualities with a fixed percentage of phosphorus by sorting the ore in the general way. Of that reason he introduced another method based on a careful research by chemical analyses in the following way. During the progress of the mining operations numerous samples are taken, the phosphorus percentage found in them is entered in a map, by the connecting of the points with the same percentage one gets a view of the distribution of phosphorus in the part of the mine in question. The quality wished for is obtained by quarrying different quantities of ore with a different phosphorus percentage and then mixing them in suitable proportions.

The mining operations being thus performed with the help of chemical analyses and accordingly in the most reliable way possible, it is rather unsuitable to use LUNDBOHM's classification quite unchanged with this work. The writer will instead take more notice of the characters of the ore which may give information of its mode of origin or explain the causes of the strange variations in its composition.

The first three of LUNDBOHM's types may very well be retained here.

Type 1, the magnetite containing a very low percentage of phosphorus, constitutes the greater part of the ore body of Vaktmästaren and occurs also in the most northerly part of Grufingeniören. Even the ore of Jägmästaren is rather similar to this type. It is black or bluish black and very lustrous on a fresh surface, quite dense and very hard, with irregularly conchoidal fracture. Small cracks are filled with crystallized quartz or with talc; veins of other minerals, especially calcite,

also occur (see p. 122). But there are no other primary constituents than the magnetite present, as the apatite quantities contained generally are too small to be visible to the naked eye. In ore that has not been subjected to any concentration the Fe percentage varies between 68 and 71 and that of P between $0,_{80}$ and $0,_{016}$. Some samples having been subjected to a simple concentration by hand show respectively [41] $70,_{80}$, $71,_{40}$ and $72,_{20}$ per cent of Fe, and $0,_{004}$, $0,_{014}$ and $0,_{004}$ per cent of P. The last one is evidently almost pure magnetite, as this mineral contains $72,_{40}$ Fe. They are general samples all of them, taken in 1896 and analysed by C. G. SÄRNSTRÖM.

Type 2. Under this type are comprehended the varieties low in apatite making up the southernmost part of Landshöfdingen and the whole of northern Professorn with the exception of a considerable area near the hanging wall. Within this area there occur, it is true, several rather dissimilar phases, but they may nevertheless be comprehended as a type compared to the rest of the ore body.

One of the characteristic features is the high oxide percentage giving the streak a more or less distinctly red colour. The ore is generally dense, with dull or scintillating fresh surface. The most remarkable feature is the abundance of rusty cavities, which are often found so near one another that the ore, as LUNDBÖHM [41] observed: »at a cursory glance resembles a badly roasted sulphide ore.» But in certain parts of the area they occur rather sparingly. They are always very irregular, often flat and thin. The »rust» coating the walls and in part filling the cavity is reddish brown to dull brown, but its streak has an ochre yellow colour. There sometimes occur »Glaskopf»-like balls reaching about 1 mm in diameter, which seem to consist of the same substance. Some of these cavities are filled with quartz (see p. 109).

Only quite small concentrations of apatite occur, but portions of varieties more rich in this mineral are interspersed here and there. Asbestos is often present in considerable quantities, chiefly in compact ore. It occurs in small patches and streaks in the same way as the apatite and often fills fine fissures. It often encloses well developed octahedrons of magnetite, which sometimes reach a diameter of several mm.

Southwards this ore type passes into another, having fewer cavities, but containing small concentrations of apatite, the oxide percentage also lessens rapidly. Otherwise this type is similar to the one just described.

Type 3. LUNDBOHM [41] writes: »Average phosphoric ore with compact, steel-like surfaces of fracture prevails in the eastern part of Bergmästaren, and is of fairly general occurence in Statsrådet, in Kapten, in the northern part of Landshöfdingen, and at other places. It appears to be perfectly pure, and it is only on a closer examination that the small crack-fillings of apatite can be discerned, though they may raise the phosphorus percentage of the ore to several tenths.»

There is not much to add to this description. But this fact ought to be emphasized, that ore of this type is only exceptionally found in great quantities but is generally mixed with varieties containing considerable quantities of apatite. A rather great quantity of the ore of Landshöfdingen seems, however, to belong to this type.

Types rich in apatite (LUNDBOHM's 4 and 5).

The types containing small quantities of apatite, generally belonging to the A, B and C qualities, are treated above and have been found to constitute only a small part of the ore body. The rest of it is accordingly more or less rich in apatite, but the percentage of this mineral is very varying; here and there phases are found, which may be classed among the above described, more pure ores, and there are continuous transitions from them to large concentrations of pure apatite. These alternations appear most beautifully on weathered surfaces.

When the percentage of finely distributed apatite is high, the ore on fresh surfaces is gray and on weathered surfaces dull black and porous. When the apatite is concentrated in quite small patches or occurs in rather large individuals, the ore surrounding these is consequently more pure and has a bright black colour. A widely distributed phase is dense, dimly lustrous on fresh surfaces, it is evidently rather rich in apatite and surrounds the large apatite masses of Bergmästaren. Similar types but with more lustrous surface are also common; the ore phases with little apatite generally have a bluish colour on weathered surface. Ore of type 3 is widely distributed in an intimate mixture with the phases rich in apatite.

By the increase of the apatite there is a transition into masses totally consisting of this mineral, which are one of the most remarkable features of the petrography of the Kiirunavaara ore. The apatite of the masses is nearly always finely crystalline, the individuals are often less than 1 mm in length. It is as a rule more or less purely white but also assumes a pinkish shade, sometimes in spots or in parallel streaks. Now and then it is dark gray. The microscopic examination shows that the former

variation is caused by small red hematite plates, the latter by finely distributed magnetite. The magnetite lumps are sometimes surrounded by a greenish apatit ezone, which lacks the hematite inclusions (fig. 27).

In a sample of practically pure apatite from Direktören, the chlorine percentage has been found to be 0,22 [40]. The fluorine has not been determined, but the apatite from Gellivare Malmberg, the composition of which for the rest is quite identical to that of the Kiirunavaara apatite, has 3,67 per cent Fl. (ibid).

The limit between ore and pure apatite is generally well defined, and a continous transition from pure magnetite ore to ore rich in apatite and lastly to pure apatite is only seldom seen. But the border is of course

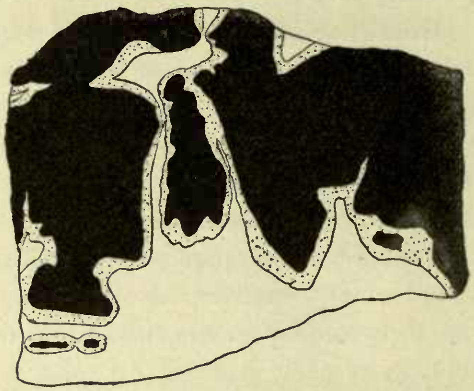

Fig 27. Ore and apatite, Bergmästaren, Kiirunavaara. $^2/_3$ of nat size. Black = magnetite; white = pink-coloured apatite; dotted = greenish apatite.

more distinct when the apatite mass is surrounded by pure ore than when it is lying in ore containing great quantities of apatite. STUTZER has pointed out a feature which he considers to be the rule, and to which he, doubtless quite justly, attaches a great importance. He writes [62, p. 587]: »Betrachtet man die Grenzverhältnisse zwischen Magnetit und Apatit genauer, so sieht man bei den meisten Stücken, dass am Kontakt der Magnetit viel dichter und gländzender aussieht, als weiter entfernt vom Apatit». I cannot, it is true, agree with him in his opinion that this should be the rule, but I have myself collected many hand specimens showing the feature in question beautifully. In one case a streak of pure apatite, scarcely 1 cm wide, runs at right angles to the schlieric alternation in the ore, the latter having the above described characters on both sides of the apatite.

There are also seen concentrations of apatite surrounded by a zone of more pure ore. Small concentrations of this kind are described by STUTZER [62, p. 587], the biggest ones seen by the writer reached some cm in diameter.

Fig. 28. Ore and apatite, Bergmästaren, Kiirunavaara. 1/2 of nat. size.
Black = magnetite; white = apatite.

The size and shape of these apatite masses is very varying. There exist all kinds of transition from groups of a few small apatite crystals to the greatest bodies of this mineral that occur here. They sometimes form irregular, sinuous and scalloped lumps with a diameter of several meters at most, or thinly tabular bodies, with about the same direction of strike and dip as the ore body as a whole, and combining a width of

Fig. 29. Ore and apatite, Bergmästaren, Kiirunavaara.
The band is 0,8 cm wide.

10 to 20 cm with a length of more than 20 meters. The irregular lumps often pass into a breccia of ore fragments cemented by apatite, and such fragments are often enclosed also in the centre of them. The tabular masses split up in the same way in the direction of strike and dip, they show transitions to »stockworks» of apatite veins; they are thus quite evidently no layers. The small apatite bodies are also generally elongated parallel to the strike of the ore mass.

Fig. 30. Ore and apatite, Bergmästaren, Kiirunavaara.
$^1/_4$ of nat. size. (See text.)

With regard to the relation between the pure apatite and the enclosed ore fragments, the following features have been observed. The fragments are often sharply angular and the apatite cannot have crystallized until the cohesion qualities of the ore were about the same as now. Such a case is seen in fig. 28 (it resembles one of STUTZER's illustrations, 62, p. 585) and in fig. 29. In the mass of ore and apatite shown in fig. 29 both minerals have been contemporaneous. To the left there appear lumps of magnetite in relatively pure apatite, in the middle there is a streak, gray on account of finely distributed magnetite and with small concentrations of this mineral at the left border. More to the right another streak appears, but the

magnetite concentrations in it (also here at the left border) are larger than in the former and more like the lumps to the left.

These figures thus illustrate the relation between the magnetite and rather great quantities of apatite, when the latter have crystallized much later than the former or is contemporaneous with it. But when the apatite has crystallized first of the two minerals, the ore has quite another appearance, being more or less regularly stratified. (See p. 99).

When magnetite and apatite are mixed in about the same proportions, very peculiar structures often occur. The magnetite often forms shells, 1 or af few mm thick, enclosing a lump of apatite, sometimes reaching several cm in diameter; these shells show now circular, now elliptical or lemniscate-shaped sections and seldom seem to be quite closed. Within

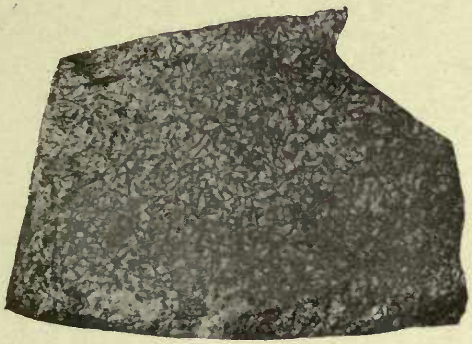

Fig. 31. Skeletons of magnetite in apatite, Bergmästaren, Kiirunavaara. Polished surface. Nat. size. Compare fig. 23.

these shells there is pure apatite, and they are surrounded by the same or by ore rich in apatite. In the latter case they are evidently similar to the rings of nearly pure ore, already (p. 94) described, but the cause of their development is in the former case rather difficult to understand.

A skeleton structure is much more common: the magnetite appears in threads or lamellæ, now grouped as foot-prints of birds, now distinctly fluidally arranged. The spaces between these skeletons are filled with apatite. The former type is seen in fig. 31 and the latter in fig. 32. Sometimes it is still more evident that real skeletons of ore are present here. the magnetite grains are arranged in long rows with short cross-bars (fig. 33): Such a system often reaches a length of 5 to 6 cm and a width of 1 cm and reminds us very much of the magnetite skeletons occurring in basalts and in slags, but in the ore the regularity is often less on account of fluidal movements. These different skeleton-forms are seen in phases with

a rather variable but always rather high apatite content, and the areas where the ore has this structure altogether may reach a diameter of 1 meter or even more. Areas with this structure often pass continuously into common ore. There exists a striking similarity between this peculiar ore structure and the arrangement of the magnetite grains in the ground-mass of some porphyries of the region, especially that of the dark rocks of Hopukka (see the description p. 75 and figs. 23 and 24), and of phases of the quartz-porphyry.

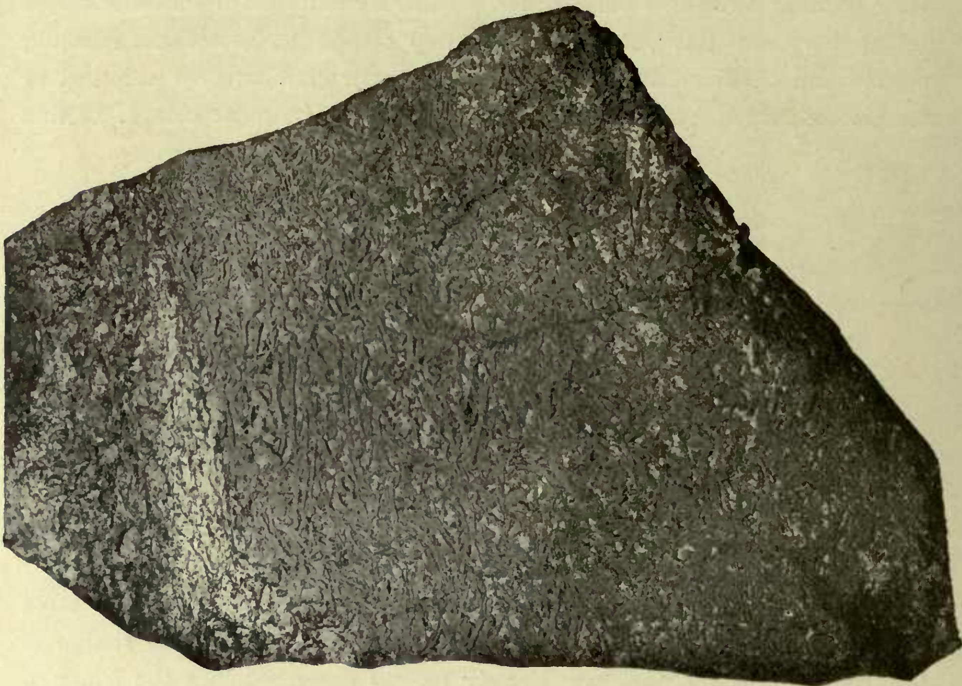

Fig. 32. Skeletons of magnetite in apatite, Bergmästaren, Kiirunavaara. Polished and etched surface. Nat size. Compare fig. 24.

The apatite is sometimes present in the shape of flattened ellipsoids having a diameter of about 1 cm at most; these ellipsoids are enclosed in a quantitatively subordinate magnetite matrix. The microscopic examination shows that these apatite bodies have the same structure as the common ones.

The ore surrounding the large apatite bodies is with regard to its apatite percentage seldom homogeneous over large areas. It generally shows an irregular schlieric alternation of phases poor in this mineral and of phases containing rather great quantities of it. On weathered surface,

ore of the former variety is therefore bright and dense, while ore of the latter variety is lustreless and porous. The schlieren generally strike about parallel to the direction of the whole ore body. The limit between the different varieties is sometimes sharply defined, but a distinct transition is often seen. Rounded lumps of one ore type often occur in the other one, but a real breccia-structure is also seen, as in a place on the summit of Statsrådet, where numerous angular fragments of relatively pure ore lie in a matrix of a dull porous one, which has evidently been originally very

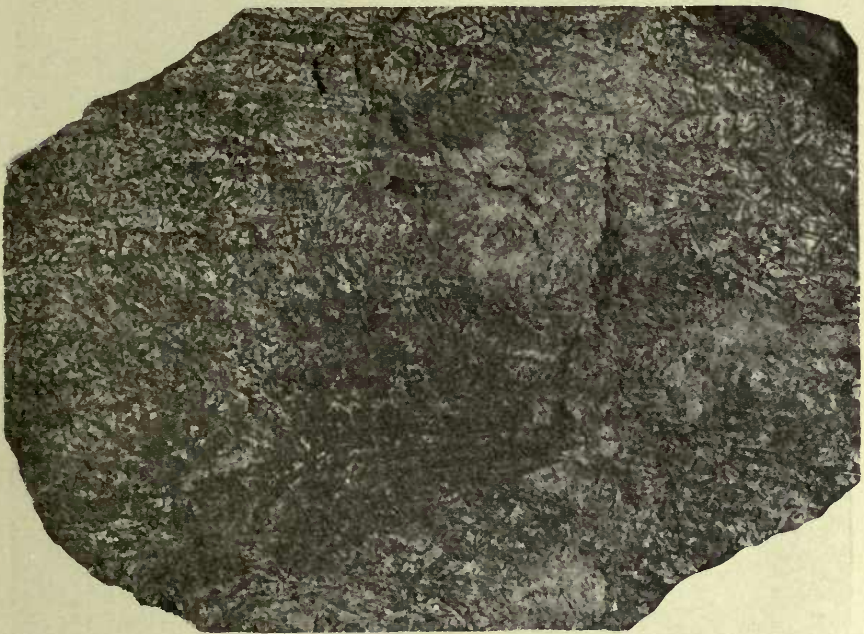

Fig. 33. Regular skeletons of magnetite in apatite, Bergmästaren, Kirunavaara. Nat. size.

rich in apatite. Dikes and veins of the purer ore are often present in the other one, but the contrary is seldom observed. These veins often come from an irregular lump of ore and generally reach a width of only a few cm. But it is probable that the peculiar, p. 86 described columnar ore constitutes a dike, and it has, as has already been stated, a considerable width.

Small concentrations of apatite are present in all these varieties, being perhaps most common in those containing rather great quantities of this mineral equally distributed. Even when the apatite percentage is rather low, there often appears a trace of a skeleton development of the small

magnetite concentrations, or there are seen shells of the purer ore, analogous to those described above.

Fig. 34. »Stratified ore», Statsrådet, Kiirunavaara. Weathered surface. Nat. size. The thin apatite layers are much weathered, but the white colour is often visible.

Fig. 35. Schlieric, rudely »stratified» ore, Statsrådet, Kiirunavaara. Weathered surface. Nat. size.

STUTZER [62, p. 588—589] describes and reproduces a dike of pure apatite cutting a mass of gray, magnetite-bearing one. The writer has found other similar phenomena, being visible, however, only under the microscope.

The microscopic examination often shows a considerable amount of apatite even in the varieties that on weathered surface appear to be rather pure magnetite. The limit between phases with a different percentage of this mineral therefore on such a surface undoubtedly appears to be sharper than it really is. The explanation is surely that when the apatite percentage reaches a certain degree, the leaching out of this mineral makes

Fig. 36. »Stratified ore», western slope of Statsrådet, Kiirunavaara. White is apatite.

a washing out of small grains of magnetite, that are detached, possible. The size of grain is of course of great importance. This is especially applicable to the type of ore we are now about to describe.

In the western parts of Statsrådet and Geologen and in isolated areas in other parts of the mountain, the ore containing much apatite assumes a decidedly stratified structure. The layers strike nearly parallel to the neighbouring foot wall contact, the dip is not known. In its most pronounced shape this variety shows a regular alternation of layers of apatite and ore, the former generally reaching a thickness of some tenths of a millimeter, the latter as a rule being somewhat thicker. See fig. 34. Among loose boulders with so thin layers there are some being about 2 dm thick, measured at right angles to the plane of stratification.

More common than this regular stratification is the phenomenon that the apatite, when occurring in tabular bodies, contains masses of the same shape of relatively pure magnetite, which appear on the surface as parallel bands; besides there occurs in the apatite finely distributed magnetite, partly concentrated in streaks parallel to the bands. Such a band is described by LUNDBOHM [41] who has observed it for 15 meters. It is about 36 cm thick.

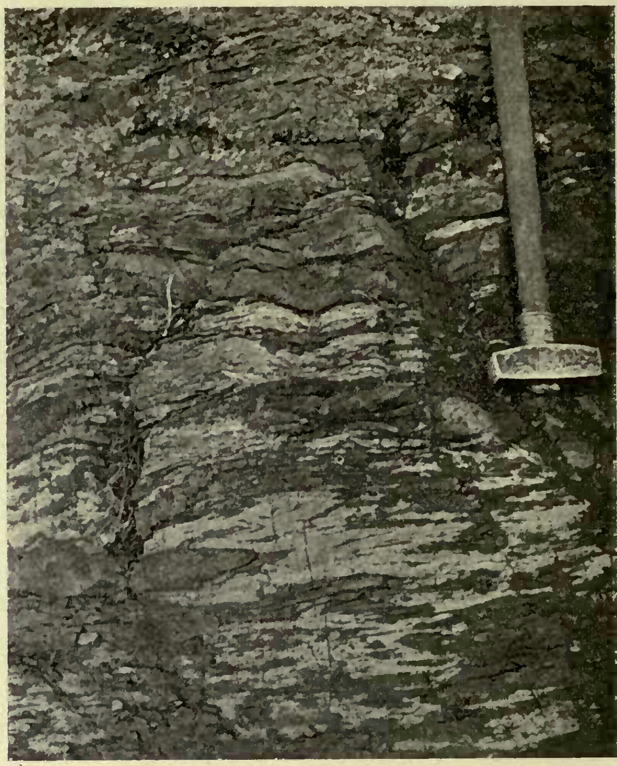

Fig. 37. »Stratified ore», Geologen, Kiirunavaara. White is apatite.

The stratified areas are scarcely as much as 1 meter wide, generally much narrower. When following them in their direction of strike they are generally found to narrow and end by the diminishing of the apatite between the ore bands. But they sometimes also end quite suddenly. In their mode of occurrence they are on the whole similar to the tabular bodies of pure apatite.

This stratified ore type shows a transition to a phase whose parallel structure is much less regular. This phase, which is shown in figs. 37

and 38 (compare also 35), is characterized by a schlieric, rudely parallel arrangement of magnetite and apatite, partly separated in layers, some of which are very curved, while those lying both above and below are quite undisturbed. These schlieric phases are, much more distinctly than the regularly stratified ones, accidental structures of ore very rich in magnetite, a fact that appears in all their relations to the surrounding, not stratified varieties.

Streaks of apatite, and more seldom veins of magnetite, cut the layers. When a fresh surface of the ore is examined, there appears to be little or no difference between the layers of apatite and those of ore. This depends,

Fig. 38. Schlieric, in part rudely »stratified» ore, vestern slope of Statsrådet, Kiirunavaara. The band is 0,8 cm wide.

as is shown by the microscopic examination, upon the fact, that the latter contains considerable quantities of apatite and to a great part belongs to LUNDBOHM's type 5.

The macroscopic characters of the »stratified ore» and its relations to other types have now been treated. Only the microscopic examination reveals some features which to a certain extent explain the development of this peculiar structure.

Octahedrons of magnetite are seen here and there, those contained in the ore of type 2 are already mentioned. On Statsrådet some reach a size of up to 1 cm, they are rugged and lying in apatite. They are sometimes altered to hematite (martite). The apatite is now and then, in druses in the large concentrations, freely developed in crystals of the shape described p. 24.

Hematite. At the description of type 2 the writer pointed out that the finely distributed hematite occurring in it in abundance, very probably is of secondary origin. But this is not the case with some occurrences of quite another kind, which are seen here and there in the mountain, but mostly on Geologen and Statsrådet. The mineral occurs there in dense or finely crystalline lumps with sharply defined outlines towards the surrounding magnetite. These lumps are nearly always rounded, they reach a diameter from 1 or a few mm up to more than 1 dm. When small they often cluster together in aggregates. There also occur, especially on Bergmästaren, more coarsely crystalline hematite lumps with less sharply defined outlines towards the magnetite; in these lumps druses are often seen.

Even more often the hematite occurs in the shape of veins. These are generally very thin, 1 or a few mm wide or even thinner, and generally very short. They often run at right angles to the longer axis of the ore body and the general direction of strike. They branch out and anastomose and often form a fine network in the magnetite. Such veins sometimes come from hematite lumps of the same kind as described above. The veins are less often some cm wide, they are then generally drusy or consist of open fissures, the walls of which are coated with hematite crystals, generally of thickly tabular habit. These veins often have the same directions as the above mentioned ones and are also generally quite short. Transition forms between these different vein types are very common. Thin veins cutting apatite masses are also seen.

Asbestos sometimes occurs in veins associated with the hematite.

Ilmenite. Crystals of this mineral, one or a few mm in diameter, have been found on Bergmästaren by A. R. ANDERSSON. It occurs on jointing planes in the ore.

Pyroxene and uralite. These green silicates are more abundant in the ore than has been supposed up till now (pyroxene was before not known as a constituent of the ore). The silicate-bearing ore may be divided into two zones, one of which follows the foot wall in great parts of the mountain, while the other one, which is a much smaller area, runs near the hanging wall on Bergmästaren. Beyond these zones, which, however, are not very sharply defined, the two silicates are almost never found, provided that one does not consider the asbestos as a product of their alteration, in which case greater part of the ore on Pojken and some other considerable areas must be classified with them. For the present,

however, we leave the asbestos out of question and need only occupy ourselves with the two zones just mentioned.

The first zone has been observed furthest south near the south end of Professorn and runs near or quite close by the foot wall of the whole of this hill. Southernmost it is a few meters wide, but immediately north of the summit (now quarried away) it reaches a width of 10 to 15 meters. The silicate is hornblende, as is shown by the microscopic examination; it occurs in equally distributed tables generally having a diameter of some mm. It is light green in colour. The individuals are often gathered in streaks, which are almost free from magnetite and resemble »skarn». Sometimes these streaks are coarsely crystalline and drusy. At the south slope of Landshöfdingen there are only seen quite small areas of such ore, near the foot wall, but on the ridge it occurs for a length of about 130 meters along the contact. The width varies between only a few and up to 15 meters. The form, size and mode of occurrence of the hornblende individuals is just as on Professorn. It is, however, especially worth noticing that the mineral is equally distributed in the ore quite independent of the higher or lower apatite percentage of the same.

In the most northerly part of Landshöfdingen and on Kapten there occurs silicate-bearing ore only in a very small quantity. On Pojken there occur streaks of hornblende but no ore with the above described structure. On Direktören there is close by the foot wall contact a zone with a width of 20 meters, containing rather much hornblende, generally concentrated in streaks; this zone is perhaps connected with the one on Bergmästaren, the southernmost parts of which hill are not open to observations on account of the moraine covering. The zone on Bergmästaren is uncovered for a distance of at least 150 meters along the contact, but it is very narrow, generally only a few meters wide. The hornblende is partly equally distributed in the ore, and partly accumulated in streaks running about parallel to the contact. The ore contains apatite in considerable quantities, partly in rather large concentrations. In these there are lying angular pieces of ore with hornblende, and of hornblende rock (skarn).

In the neighbourhood of the foot wall on Statsrådet there also occurs rather much hornblende in the ore, mostly gathered in parallel streaks. On northern Geologen the mineral is rather common, generally having the shape of very small individuals and mostly occurring in bands and streaks running parallel to the contact. While the greater part of this hornblende or its mother mineral, the augite, doubtless is a primary con-

stituent of the ore, this is not quite certainly the case with the up to 1,5 meter wide masses of hornblende occurring here and there on the contact. As will be more emphasized in a following chapter, this hornblende occurs in such a manner that one has good reasons for supposing that it is a product of contact metamorphism.

The zone nearer the hanging wall, on Bergmästaren, runs at a distance of about 25 meters from it and is separated from it by ore quite free from silicates. It has a length of about 150 meters and a width of about 10 meters. It is perhaps connected with a variety on Direktören, occurring at about the same distance from the contact and containing a rather considerable quantity of hornblende in quite small individuals. While the silicate mineral in the above described occurrences, as far as the writer knows, is a hornblende, often fibrous, there occurs on Bergmästaren a pyroxene, more or less transformed into uralite. This difference is, however, seen only under the microscope. The pyroxene occurs, as the hornblende, i tabular individuals, their largest diameter varying from a few mm up to 1 cm or sometimes more. They are generally very thin, often only some tenths of a millimeter thick. They are as a rule rudely parallel arranged; in sections at right angles to the predominating crystal face some individuals are seen to be curved, but not their neighbours, therefore this structure cannot depend on later pressure but must be of primary nature and have originated during the movements in the ore mass before its solidification. An ophitical grouping of the crystals is also very common.

The pyroxene is, like the hornblende of the above described occurrences, gathered in skarn-like bands, partly associated with apatite. Its distribution seems, however, on the whole to be independent of this mineral.

Biotite. This mineral is on the whole rather rare and occurs only seldom in macroscopically visible plates. On Landshöfdingen the writer has found an intergrowth of magnetite and black biotite, resembling the ore lamellæ in apatite.

Titanite. LUNDBOHM mentions [41] that this mineral has been found on Jägmästaren, and the writer has been told that it has also been found in the more northerly parts of the mountain, but has hinself only seen it at the foot wall contact.

Tourmaline. This mineral, which occurs on the contact with the wall rock on Landshöfdingen (see p. 115) exists within the ore body in one

place only, viz. in northeastern Geologen, some meters from the contact. It occurs in drusy streaks and flattened lenses, some dm long but only a few cm thick, and following the strike and dip of the ore body. It forms thick prisms, black in colour and reaching a length of some mm.

Asbestos is often present in streaks and patches, being sometimes also rather equally distributed in the ore, or still oftener in the apatite concentrations. It is finely fibrous.

Other minerals. When leaving the real fissure veins occurring here and there in the ore body out of the question, we have only a small number of other macroscopically visible minerals to attend to, and they are all of them of secondary origin. Calcite fills cracks and cavities in the ore, especially in Professorn at greater depths. Siderite occurs on Kapten, partly in crystals, about 1 cm in length, embedded in green chlorite. The latter mineral is not uncommon, and generally occurs in quite small flakes. Talc is rather often seen, it is an alteration product, developed from the pyroxene and the amphiboles (hornblende and asbestos). —

Luossavaara. This ore is less rich in interesting features than that above described. The apatite content is on an average lower, and there are accordingly not so many different relations between this mineral and the magnetite. Primary hematite is also more rare and minerals of the pyroxene-hornblende group are altogether missing, but titanite occurs here in a considerably greater quantity than in Kiirunavaara. The greatest part of the ore having been covered with thick moraine there is no etching due to the action of meteoric waters.

The relation between magnetite and apatite. In the open cut at the southern foot of the mountain, the ore is finely crystalline or dense, bluish black or pitch black in colour, and lustrous. Only close to the foot wall, in a zone reaching a width of at least 10 meters, there occurs a type more rich in apatite; it is dense and of a grayish black colour, here and there within it irregular concentrations of white apatite are found. Druses with apatite crystals are also present. (A similar mass of ore very rich in apatite partly separates the A-ore of Vaktmästaren from the foot wall rock).

The ore both south and north of the summit is principally similar to the first of these types, it is finely crystalline or dense, black with a more or less bluish tinge, and often lustrous. The percentage of finely distri-

buted hematite is in part rather high. As rusty cavities occur here and there, this ore is rather like type 2 of Kiirunavaara.

Irregular concentrations of finely crystalline, white or pinkish apatite are not uncommon, but never reach dimensions equal to those occurring in Kiirunavaara. In the most northeasterly, less well known parts of the ore body such apatite masses are, however, present in considerable quantities. Skeleton structure of the magnetite seldom appears.

Hematite. Besides being finely distributed in the magnetite mass, hematite sometimes occurs in small veins and in druses.

Asbestos. This mineral occurs in the ore of Luossavaara in the shape of small streaks and patches, often containing octahedrons of magnetite. It evidently occurs in the same way as in Kiirunavaara, (especially as in type 2).

Biotite. This mineral is much more common here than in the ore of Kiirunavaara, but is always present in small quantities only.

Titanite has been observed only in the already mentioned open cut at the southern foot of the mountain, where it, however, is rather abundant. The TiO_2 percentage in the ore of Luossavaara is generally higher than in Kiirunavaara, its maximum is 1,36. The titanite partly occurs enclosed in ore, having the shape of rather well idiomorphic crystals reaching a length of up to 5 cm, and partly, this being the more common thing, in druses, but then, however, often sticking out into the surrounding ore. Also in this case the crystals reach a length of several cm; they are thickly tabular, the same forms as of the nodule-forming titanite appearing to be developed. Small crystals are sometimes seen to penetrate the longer ones. The crystals are also sometimes lying on one another in an imbricate manner. The titanite is sometimes embedded in apatite, in other cases it adheres to crystals of this mineral.

In the ore there occur a few small veins of chlorite, having probably developed through the alteration of biotite, they contain numerous crystals of titanite. These crystals and many of those occurring in the druses are quite fresh and lustrous, but as a rule the mineral has an ochre-yellowish surface due to weathering.

Especially the pitch black variety of the ore is, when containing titanite, quite similar to the dike-forming ore described p. 55.

Other minerals. Quartz, talc, chlorite and calcite occur in very small quantities and are probably all of secondary origin.

Microscopic characters.

Description of the crystallographic and optical properties of the minerals.

Apatite. This mineral is in thin sections always quite colourless, and no pleochroism is seen. Sections cut at right angles to the c axis show a biaxial figure when examined in convergent light, but the indistinctness of the figure renders an exact determination of the angle impossible.

It occurs in elongated grains or in prisms the length of which is from 2 to 5 times the width. The length reaches from 1 or a few tenths of a millimeter up to 1 or a few mm. The different individuals having impeded the development of one another, idiomorphic form is seen only when, as often happens, an individual occurs as a phenocryst among the others, but even then only the prism faces are well developed.

A rather irregular parting parallel to the pinacoid is common.

Inclusions occur in varying, generally great, quantities especially in the central parts of a crystal. They are acicular, the length being from 2 to 12 times the width, and have quite straight sides. At the ends they are limited by faces at about right angles to their longer axis. They are quite parallel to one another and to the c axis of the apatite. The size is very varying but generally reaches at least some hundredths of a millimeter. As these inclusions are embedded in the apatite, their optical properties may only partly be determined. The difference in refraction between the two substances is rather considerable, but it is impossible to decide which of the two has the highest one, it is probably the inclusions. The interference colours are rather vivid, the extinction is only seldom coincident with the directions of vibration in the nicols. The inclusions can therefore not be zircon as has before been assumed by the writer [14] concerning similar bodies in the dike-forming apatite (see p. 142). Small red plates of hematite are also often enclosed in the apatite.

Zircon is rather often present in the apatite concentrations. It is known by the following qualities: colourless, refraction rather much higher than that of the apatite, strong birefringence, extinction parallel to the crystallographic axes, uniaxial, optically positive, shows two cleavage systems at right angles to one another, often quadratic outlines or prisms with terminating pyramide faces. It also very often occurs in irregular grains, without any crystal habit. The individuals generally reach some tenths of a millimeter.

Hematite. The above described occurrences of this mineral show almost no new features under the microscope. But it is worth observing that apatite often occurs in them, as well in the lumps as in some veins, in the same way as in the magnetite. Besides, the hematite occurs in the shape of small red plates (»Eisenglimmer») together with the apatite, especially in the large concentrations of the latter, giving them, as is already mentioned, a pinkish colour. It is then mostly found in the parting cracks or between the apatite individuals, sometimes also enclosed in the latter.

The red coating of the cavities in the ore of Professorn is under the microscope seen to be partly anisotrop, its colour is in thin sections a somewhat darker red than that of the just mentioned kind of hematite. It often forms a fine network, extending from one wall to the other in a cavity.

Augite. The pyroxene of the silicate-bearing zone of Bergmästaren is a diopsidic augite, in all principal features analogous to the one occurring in the syenite and the two groups of syenite-porphyries of Kiirunavaara. It is in thin sections almost colourless or pale yellowish green. Beside the normal prismatic

cleavage there sometimes occurs a very irregular parting at about right angles to the flattening of the crystal. It has probably developed through ruptures during the period of crystallization. The pinacoid (010) is the predominating form of these tabular crystals, while (100) is predominating with the examined augites of the porphyries. The size varies generally between a few and 10 mm.

The augite is generally somewhat altered. This alteration is often of a distinct uralitic nature and has resulted in the development of an almost colourless hornblende, which often totally replaces the augite. In other cases chlorite, talc and epidote are present, probably developing partly directly from the augite, partly from the hornblende.

The *hornblende* of the silicate-bearing zone along the foot wall contact is in its optical properties similar to the uralite of the ore of Bergmästaren. It is also fibrous. This hornblende is very probably always of uralitic nature. A closer examination of the optical properties shows: $\mathfrak{b} = b$; $\mathfrak{c} : c =$ about $20°$, optical character positive; pleochroism weak with the following colours: $\mathfrak{a}$—colourless:, $\mathfrak{b}$—pale green; $\mathfrak{c}$—pale bluish green.

The tabular habit of the crystals is in this zone scarcely as strongly developed as on Bergmästaren. The size is also smaller, generally reaching only a few mm.

Asbestos (actinolite). This mineral is in thin sections colourless or pale yellowish, its refraction is somewhat lower than that of the apatite, while the birefringence is about the same as that of common hornblende. It shows the usual amphibole cleavage and is very fibrous. A very weak pleochroism is seen, the strongest absorbed ray is the one parallel to $\mathfrak{c}'$, the angle $\mathfrak{c} : c$ is about $20°$. The mineral is accordingly an amphibole poor in iron, of the composition of the tremolite or the actinolite.

It occurs in acicular individuals, often arranged in bunches, and generally embedded in apatite. The writer has not been able to determine whether it is of primary origin or developed from the other amphibole. The somewhat brighter colour and generally bigger, more compact crystals of the latter is the chief difference between the two, but there also occur types that are a medium between them. This fact seems to be in favour of the former alternative, but on the other hand one ought to remember the asbestos developing from the nodule-forming hornblende of the porphyries of Professorn.

The writer is, however, most inclined to consider this amphibole of the apatite masses as a primary constituent, while some more finely fibrous aggregates filling small cracks etc., are doubless secondarily developed.

Mica. Brownish green biotite very similar to that of the syenite (see p. 9) is rarely seen in the ore of Kiirunavaara, being, as appears already macroscopally, commoner in that of Luossavaara. It generally occurs in small plates.

In the apatite concentrations there is often seen a yellow mica, it now occurs in the same manner as the thin plates of hematite, now in larger individuals and gives the apatite mass a yellow or yellowish brown colour. It has a distinct cleavage system and parallel extinction, the refraction and the birefringence are at least very nearly the same as those of the biotite. It is nearly uniaxial. The pleochroism is comparatively weak, in different shades of yellow, almost golden. A similar mica was found by FERMOR [10] in a little known apatite-bearing ore from Bengal.

Here and there in the apatite there occur small colourless plates, showing rectangular sections. They are probably muscovite, but the small size of these scattered individuals makes a positive statement quite impossible; they might also be talc.

The *titanite* offers nothing of special interest. *Orthite.* Only two small grains are found (in slides from different parts of Kiirunavaara). The mineral is allotriomorphic and in its optical properties similar to the orthite of the porphyries.

Talc is rather often present in streaks and patches, forming small flakes or sometimes sphærulitic aggregates of larger individuals, it often surrounds the apatite crystals. It has very probably always developed by the alteration of an amphibole mineral or perhaps sometimes of a mica. The green *chlorite*, which occurs in the same way, but is less abundant, seems to have a similar origin. It often forms very regular small sphærulites.

Fig. 39. Apatite mass, Geologen, Kiirunavaara. Nic. +. Magn. 14 times. Shows the structure of the pure apatite masses in the ore.

Quartz occurs — leaving the small fissure veins out of the question — exclusively in the porous ore of Professorn and southernmost Landshöfdingen. Single individuals are never found, but always many grains clustered together, these quartz patches are restricted by the crystal faces of the surrounding magnetite. But crystals of this mineral are sometimes also enclosed in the quartz.

There is scarcely any reason for supposing this quartz to be a primary constituent of the ore, though, as will be shown further on, the mineral occurs as a constituent of the other ores of the region, which in their mineralogical characters are rather similar to that of Kiirunavaara. In the places where the quartz is most abundant, the ore is porous and uncommonly permeable, and the quartz has probably replaced apatite or filled open cavities. The primary quartz in for instance the apatite dikes of the quartz-porphyry, which has probably been

subjected to the same degree of regional metamorphism as the ore body, nearly always occurs in large areas, not as groups of rounded grains.

The *calcite* is limited to the parts of the ore which have been sheltered against weathering due to the action of atmospheric waters. There exists no real reason for supposing it to be of primary origin, as it is always filling fissures or cavities, and never occurs equally distributed in the magnetite mass.

The same may be said of the *pyrite*, which is often found together with the calcite, but always in very small quantities. It is, however, not impossible, that a few grains of this mineral may be primary.

The structure.

In the concentrations of apatite the structure is generally quite massive, or there appears a rudely parallel arrangement of the individuals. The latter is especially the case when the prisms are rather elongated. The outlines between the different crystals are never complicated. The usual crystal habit is already described. A typical structure is seen in fig. 39.

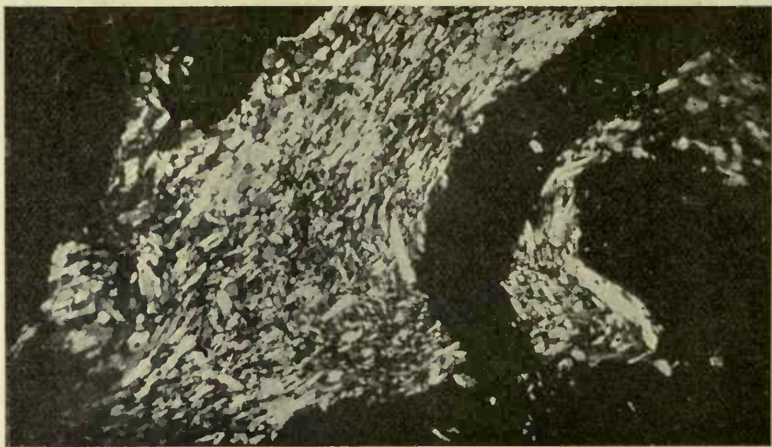

Fig. 40. Trachytoidal flow-structure in apatite, eastern Geologen, Kiirunavaara. Nic. +. Magn. 14 times. The black areas are magnetite, except the band between the apatite areas, which is due to a crack in the apatite.

The grain is varying, in some slides the average length is some mm, but as a rule it is only some tenths of a millimeter. Porphyritic structure is not rare, the phenocrysts may then be up to 10 times as large as the grains constituting the groundmass (compare fig. 41).

The grain often varies very suddenly, the more fine-grained parts then occurring as schlieren or as sharply defined veins in the others. When this is the case the c axes of the crystals often are quite parallel to one another, and in curves and bends a very beautifully developed *trachytoidal flow-structure* is seen, being sometimes still more marked by narrow laths of magnetite which are embedded between the apatite crystals. Figs. 40 and 41 show these phenomena.

As far as the writer knows, such a structure has never before been observed in »apatite-ore» [1]. Its appearance has of course a very great significance to the question of the mode of origin of these ores.

[1] STUTZER [62] describes from Ekströmsberg similar phenomena occurring in small apatite concentrations in the porphyry.

When the apatite encloses finely distributed magnetite grains, it is generally more fine-grained than in the parts free from such inclusions.

When constituting only a small part of the apatite-magnetite mixture, the magnetite generally occurs in idiomorphic crystals with a size of 1 or a few tenths of a millimeter. If the proportion of the mineral increases, these crystals run into each other and the most common structure of ore relatively rich in apatite originates: the apatite occurs in single individuals, or more often in groups of some individuals, always bounded by the crystal faces of the surrounding, finely crystalline magnetite mass.

Fig. 41. Apatite, western Geologen, Kiirunavaara. Nic. +. Magn. 14 times. A schliere-like vein of fine-grained apatite, showing trachytoidal flow-structure, in a more coarse-grained, porphyritic mass of the same mineral.

The relative age of the two minerals is accordingly the same as we have before found to be the common one between the concentrations of the two minerals taken as a whole, viz. between the apatite bodies and the purer ore.

The magnetite skeletons, mentioned p. 95, have jagged outlines and are apparently aggregates of crystals.

When a rudely banded structure is macroscopically visible in the apatite-magnetite mixture, the magnetite mostly occurs in aggregates of crystals, much elongated and lying between the parallel arranged apatite individuals. These magnetite lumps sometimes have a shape as if they were filling fine fissures; in one case such a streak has been seen to run at right angles to the parallel structure, nevertheless it does not seem to cut the parallel bands but is connec-

ted with them. This kind of structure is evidently depending on the fact that the magnetite has crystallized later than in the first described case, its distribution has accordingly been determined by the apatite, but this mineral has only exceptionally been capable of impeding altogether the development of crystal faces in it. See the relation between feldspar and magnetite in the groundmass of many phases of magnetite-syenite-porphyry! Transitions from this structure form to the one before mentioned and to the following one occur.

In the »stratified» ore these features are still more pronounced. When regarding a slide of such ore, cut at right angles to the plane of stratification, one is surprised by finding that the difference between the layers, which is so pronounced in hand specimens, here is very much reduced. The fact is that the

Fig. 42. Apatite, Bergmästaren, Kiirunavaara. Ord. light. Magn. 14 times. Idiomorphic magnetite crystals are lying in the apatite. To the left hand of the figure there is also a net of red hematite, between the apatite grains or on the cleavage cracks.

»magnetite layers» are very rich in apatite, the reverse is also true, but not in quite as high a degree. The apatites have their usual elongated shape and are almost parallel to one another. In the »magnetite layers» they enclose numerous small crystals of the ore mineral, but the bulk of the same is concentrated in jagged, elongated lumps between the apatite prisms. In the »apatite layers» the case is quite analogous, the difference is only that the magnetite percentage is much lower and that the apatite individuals are considerably bigger than in the former. Compare fig. 66. In slides, cut parallel to the stratification plane, the apatite crystals appear to be less regularly parallel arranged.

We find accordingly, that *the fine stratification in the apatite-magnetite*

mixture occurs when the former mineral has crystallized a considerable time before the bulk of the latter.

A very peculiar structure occurs in a small area at southern Landshöfdingen, quite near the foot wall. To the naked eye this variety appears to consist of a rather pure magnetite, with flattened lenses of apatite. These tables are nearly elliptical with sinuous borders, they reach a length of about 1 cm and a thickness of some mm. Under the microscope several small inclusions of magnetite are seen in the apatite, but the outer limits of the apatite tables are nevertheless sharply defined towards the surrounding magnetite mass. Yellow mica in quite small flakes is abundant in both of them. In ordinary light the

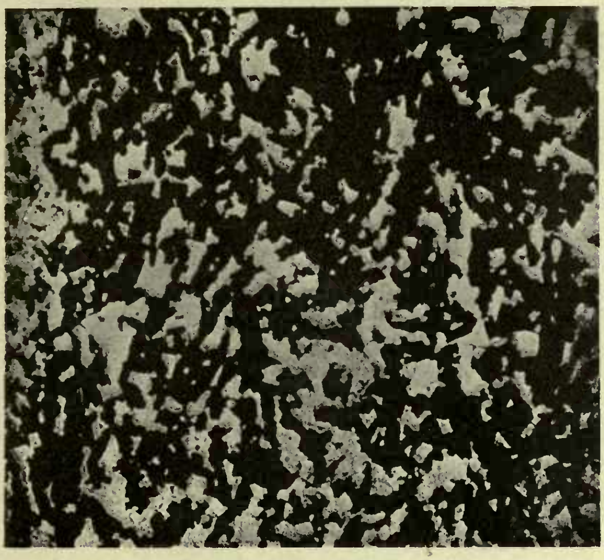

Fig. 43. Ore, Bergmästaren, Kiirunavaara. Ord. light. Magn. 14 times. The apatite has crystallized somewhat before the magnetite.

apatite appears to be composed of numerous grains, but between crossed nicols it is seen to consist of only a few fields with straight outlines towards one another and radially grouped. This is evidently a kind of sphærulitic development of the apatite.

The *augite* and the *hornblende* occur, as is already mentioned, in the shape of tabular crystals. They very often enclose single magnetite crystals or groups of crystals, sometimes coherent with the surrounding magnetite mass. Though these silicate minerals show a tendency to idiomorphic development and form big crystals with only small inclusions of magnetite, the outlines of the individuals are generally jagged, doubtless depending on the development of crystal faces in the surrounding magnetite. Stutzer, who describes and reproduces hornblende from the ore of Landshöfdingen, considers these irregular outlines to be caused by magmatic corrosion. To the writer it seems to be natural to suppose that the silicate mineral has begun crystallizing somewhat before the magnetite, but little corrosion having taken place afterwards. Inclusions of apatite occur very seldom.

As has already been stated, the tabular crystals are about parallel to one another or are ophitically arranged.

A slide of the ore with streaks of hornblende, from the silicate-bearing zone of Statsrådet, shows that the hornblende occurs ophitically in the apatite-bearing ore between these streaks, but within them it is associated with apatite and occurs partly in fibrous columns. In its mode of occurrence it therefore shows transition forms to asbestos, which, as is already mentioned, occurs especially in the apatite concentrations.

Fig. 44. Slightly uralitized augite in ore from Bergmästaren, Kiirunavaara. Ord. light. Magn. 14 times.

This *asbestos* is always very fibrous and occurs chiefly in bunches enclosed in apatite, sometimes it is, however, developed as a felt enclosing crystals of the other mineral.

The *zircon* occurs in almost all ore types, even in the »stratified» one, but it is nearly always enclosed in apatite. Here it is not associated with any red pigment.

Other minerals are of no interest with regard to the structure.

The boundaries of the ore bodies.

Kiirunavaara, foot wall. In the exposures on Professorn and Landshöfdingen the contact is generally rather distinct and quite straight, with few irregularities. The ore immediately adjacent to it belongs as a rule

to the hornblende-bearing phase, but rather pure magnetite is also sometimes seen quite close to the contact. Skarn of hornblende occur here and there on the border, but only in very narrow streaks, very little broader than those observed in the ore further off from the contact. In several places on Landshöfdingen there occur on the contact, or in the ore immediately adjacent to it, irregular masses of sericite and felt-like green chlorite with cavities more or less completely filled with black tourmaline in prisms reaching a length of up to some cm. The microscopic examination also shows apatite and magnetite. The tourmaline shows the following pleochroism: O = bluish green, E = pink; absorption $O > E$. It occurs not only in the druses but is also distributed in the sericite and chlorite mass.

Small parts of rock are enclosed in the ore quite close to the contact. Dikes of ore interweave the wall rock. Some of them contain much hornblende and resemble the ophitic ore. Most dikes reach a width of only one or a few cm, some are still smaller. In some cases much magnetite (in idiomorphic crystals) has been observed in the porphyry just close to the dikes. In other cases they are very sharply defined. Cracks in the magnetite are filled with calcite, quartz and biotite.

The greater part of these dikes are evidently younger than the rock and geologically associated with the ore. As has been already (p. 25) described, there also occur streaks of partly the same composition, which almost ought to be considered as elongated nodules. It is often difficult to determine to which of these groups a magnetite vein belongs.

In the most northerly part of Landshöfdingen the contact has not been open to examination until quite recently, and therefore no description can be given.

On Kapten there is a small exposure. The ore contains near the contact several small streaks of rock. The microscopic examination shows a mixture of magnetite and albite, with much apatite and some brown biotite. The albite occurs in individuals reaching a size of 0,2 to 1 mm in diameter. The magnetite and the apatite are idiomorphic towards it. It is very uncertain whether this albite ought to be sonsidered as a constituent of the ore mass. As the mineral, however, has been found nowhere else in it, it seems to be more correct not to do so. It is rather probable that the phenomenon depends on assimilation of a part of the wall rock by the ore.

For the rest the contact is but little exposed south of Geologen and

shows nothing very remarkable. The wall rock is generally quite unaltered until close by it, where it sometimes contains much hornblende.

The area of Geologen-Grufingeniören is very well exposed by mining operations. Beside the »older» syenite-porphyries, which are of the same kind as the foot wall of the parts as yet described, there also occurs syenitic dike-porphyry in two groups of different ages. One such body No. 10) breaks through the »older» porphyries just west of Geologen and extends as a sheet, forming the wall for a short distance. On Grufingeniören there is a similar porphyry of the same age (No. 11), but it is doubtful whether it has ever been connected with the former. The two dikes (Ns. 12, 13) cutting the ore are younger than these sheets.

The ore body is evidently younger than all the syenite-porphyries with the exception of these two dikes. Its outlines on Geologen are, as is shown on the map, very complicated. This partly depends on the fact that some of the ore dikes intruding the porphyry lie almost horizontally. As a rule, however, they dip steeply to the east.

Just north of the greatest porphyry dike the ore inserts a spur into the foot wall. This spur changes into an ore breccia which runs almost parallel to the main ore and is reunited with it immediately below the mountain.[1] In all places where it is exposed, it marks the border between the two different syenite-porphyries. Even in the railway tunnel it follows the same plane.

In the southernmost part of Geologen the contacts between ore and barren rock are always very sharply defined. Especially in the areas surrounded by ore on all sides, the porphyry is interwoven with dikes of ore, often rich in apatite or hornblende. The rock often has a green colour, evidently because of the development of secondary hornblende in great quantities. The feldspar mass is sometimes almost entirely replaced by this mineral. The examination of a slide shows that pale green, highly fibrous hornblende impregnates the groundmass, while the feldspar phenocrysts are fresh.

In the northernmost parts of Geologen the contact is less complicated: The ore is rich in hornblende, which is often concentrated in narrow streaks running parallel to the border. On the contact the same mineral forms felt-like masses reaching a width of up to 1,5 meters. This

[1] The latter statement is based on measurings made by H. KRAEPELIEN, m. e.: the excavation had to be filled after the work was finished and the writer has therefore not been able to study this area in person.

skarn contains remnants of unaltered rock and is evidently a highly amphibolized porphyry. Titanite crystals reaching a size of up to some cm in diameter are often seen in it. The microscopic examination shows that these titanites are skeleton-like. Calcite is present in small quantities in the skarn and so is also some epidote, probably developing from the hornblende.

Near the greatest porphyry dike there occurs a transition from the fresh rock to the ore in the following manner. To begin with, there occur small dikes of magnetite and hornblende in the porphyry, they grow more numerous and wider, and the result is an ore larded with small rock fragments, especially isolated feldspar phenocrysts, and then follows more pure ore. The width of the whole border zone is 1 or 2 meters. The rock fragments are perhaps dike porphyry, but this cannot be determined on account of the strong alteration.

The great porphyry dike (No. 12) shows but few traces of metamorphism. Quite close to the contact with the ore it contains rather much hornblende and magnetite, but this zone is only some cm wide. It is also possible that these minerals are partly of primary origin, forming a basic border zone. The dike cuts the schistosity of the ore at almost right angles, but bends after 8 or 10 meters and follows it on the contrary for a short distance. The little »bay» south of the main dike is connected with it by a band consisting almost exclusively of hornblende, but only one or a few dm wide. No. 13 appears at the surface as a broadly triangular area. In the adits it is seen to continue westwards as a narrow band, never reaching the present surface. Its contact with the quartz-porphyry is covered. In Geologen, near the foot wall, there was exposed in 1909 a dike which probably is of the same age as No. 13.

North of the dike, the ore is schistose and contains streaks of hornblende, just as at the southern side. This parallel structure runs parallel to the border. In the above mentioned projecting spur there occur similar streaks of hornblende and also fine layers of apatite. This stratification as well as the rather irregular jointing run in the direction of the spur. Both in this spur and in the ore breccia, which is its continuation, the magnetite is much mixed with hornblende, which in spots is developed as a coarsely crystalline skarn; there is also seen some apatite. Often, the ore predominates over the enclosed fragments, but breccia of this kind passes, especially to the east, into systems of straight or winding

dikes of magnetite and hornblende. Their mode of occurrence resembles the phenomena on Geologen, which are already described, and the ore breccia of Tuolluvaara (see fig. 63—65). No very considerable amphibolization of the rock has taken place.

On the foot wall contact of the main ore body a similar ore breccia occurs here and also further to the north. Its width amounts to a few meters at most.

In diamond drill holes these two ore breccias have been observed even at the greatest depths examined. Small areas of the same nature occur perhaps also within the dike-porphyry sheet between these two main zones.

North of the place where the ore breccia zone is united with the main ore body, i. e. north of Vaktmästaren, there occur in the middle of the ore four »horses» of rock, the largest one reaching 25 meters in diameter. The foot wall contact is generally sharply defined. In a place there occurs a short apophysis from the ore.

Kiirunavaara, hanging wall. This contact is not as well exposed as the precedent one. At the south-eastern end of the ore of Professorn — which is separated from that of Jägmästaren — there is a small excavation. The quartz-porphyry close by the contact is interwoven with veins of magnetite and hornblende, the microscopic examination also shows titanite. The rock is somewhat amphibolized.

At some distance from the hanging wall, the ore encloses a lenticular rock area, some ten meters in length. The rock is dense and usually of a pinkish colour, often containing schlieren rich in magnetite. It seems to grade into normal ore. The microscopic examination shows the following. The rock is extremely rich in apatite, which constitutes nearly half its volume, further there is (in the slide examined) seen much magnetite and albite. These three minerals occur as a kind of phenocrysts in a very fine-grained feldspar groundmass (perhaps containing a little quartz). The apatite occurs in irregularly rounded grains, $0{,}_1$—$0{,}_3$ mm in size. It is concentrated in bands. The crystal aggregates of magnetite reach the same size and occur together with the apatite. The albite individuals occupy the spaces between the apatite and magnetite grains, or form badly idiomorphic phenocrysts in the feldspar groundmass. Their size is usually about $0{,}_1$ mm. Zircon and orthite are also seen.

The next good exposure is on Kapten. The contact is well defined, the porphyry immediately adjacent to it is rich in hornblende.

In a small exposure on Direktören the limit is not so very distinct; there occurs a schlieric mixture of porphyry, magnetite and hornblende, reaching a width of about 1 dm. The examination of a slide shows that the porphyry is partly the same as usual, but partly very rich in crystal aggregates of magnetite, the structure then being rather similar to the ore described from the foot wall contact on Kapten.

On the southern steep of Statsrådet, there is a band of rock, dipping steeply to the east. The rock is dense or fine-grained and of a white colour, but often contains large hornblende crystals. There are also seen schlieren of ore, and the rock seems, as the occurence at Professorn, to grade into the surrounding ore mass. The examination of a slide shows an aggregate of albite individuals, varying in size from 0,1 to more than 1 mm, with very curving and irregular outlines. Fine cross-twinning is often seen. Besides, there are seen idiomorphic crystals of magnetite, and some apatite.

In the open cuts of the northern end of the mountain, the contact is always sharply defined and the wall rock is generally unaltered. On the border there sometimes occurs a narrow zone of ore breccia, rounded or sinuous quartz-porphyry lumps enclosed in magnetite. Numerous magnetite dikes have been observed in the porphyry at a distance of some 10 or 20 meters from the contact, but they often contain much quartz and are not connected with the main ore. They belong to the magnetite dikes of the quartz-porphyry (see p. 148).

STUTZER describes [62, p. 569] the development of quartz and biotite as secondary products in the porphyry at the level 175 in Vaktmästaren. Such an alteration occurs, however, only locally, the wall rock being as a rule quite fresh. The same writer has observed [62, p. 569] magnetite on the cleavage cracks of a feldspar phenocryst.[1]

Some hundred meters north of Vaktmästaren a railway cutting offers a good opportunity of studying the contact, which is here marked by a mass of yellowish quartz, about 15 cm wide. The porphyry just outside it is impregnated with pyrite, but otherwise fresh.

Luossavaara, foot wall. At the southern slope of the mountain this contact is rather sharply defined. The syenite-porphyry is interwoven with magnetite dikes. As has been described in another chapter, there occur in this place numerous dikes principally of magnetite, which accor-

[1] He says that the same phenomenon occurs at the foot wall contact, but gives no information as to the locality.

ding to the opinion of the writer ought to be regarded as segregations from the porphyry. As in the case of the dikes of the foot wall of south Kiirunavaara, it is often difficult to settle, to which group a vein belongs. Only very few large dikes are connected with the ore body, those are evidently apophyses from it and not segregations relatively in situ as the veins of the other group.

Nearer the summit the contact is accentuated by a band of scaly chlorite, reaching a width of some dm. Right west of the highest summit the ore inserts a dike into the wall rock. This dike has a width of about 1 meter and is about 10 meters long, it deviates very little from the direction of the main ore and together with the latter encloses almost entirely an area of porphyry. The chlorite mass has been observed on all contacts; the one along the contact of the main ore and the one bordering the dike on the west cohere and then continue as far as the foot wall contact is exposed. Beside chlorite there are seen in this »sköl» schlieric lumps and patches of magnetite, lumps of quartz and, more sparingly, needles of black tourmaline. North of the above mentioned junction, white quartz is the dominating mineral, and there are also present single crystal plates of hematite and small red feldspars. Chlorite and magnetite are, however, seen in spots even here. The width of this quartz mass amounts in places to more than 2 meters. Quartz veins run into the ore body and surround angular ore areas reaching a length of up to a few meters.

Even at the summit the syenite-porphyry is interwoven with small magnetite veins.

North of the summit, the foot wall is exposed for a little width only. The rock is very rich in magnetite, which occurs chiefly in veins and streaks, but also in nodules. It is very difficult to settle, whether all this magnetite is a primary constituent of the rock or if part of it is a product of contact metamorphism caused by the ore body. In one place, this magnetite-bearing rock is exposed for a width of some meters; here there are also seen areas within it of a red rock brecciated by magnetite veinlets, and of a pink, quite dense one, abundant in large crystal aggregates of magnetite. The former is a porphyry with fine-grained groundmass, all the feldspar is albite. The magnetite occurs in coarsely crystalline lumps and strings and seems to be a primary constituent of the rock. Together with it there are seen some quartz, biotite and apatite. The last mentioned rock is rather similar, but the size of the feldspars is

widely varying, being on a whole somewhat larger than in the former. The magnetite occurs in relatively large, idiomorphic crystals.

Luossavaara, hanging wall. In the most southerly exposure there have been observed on the eastern boundary of the ore body a mass of drusy quartz and scaly chlorite, a few dm wide and larded with needles of tourmaline, which are often gathered in drusy groups. The phenomenon resembles the one described above from a part of the foot wall contact of the same mountain and is almost quite similar to the contact mass at the foot wall of Landshöfdingen, Kiirunavaara.

Further east there appears a breccia of a peculiar kind. It consists chiefly of more or less angular fragments of quartz-porphyry, embedded in a matrix of impure magnetite ore. Apatite is sometimes also present and the phenomenon has then rather the character of a schlieric mixture of ore and porphyry. This zone is a few dm wide. The examination of a slide shows that the porphyry is interwoven with irregular and diffuse veins of magnetite (idiomorphic), quartz and albite. The albite individuals have very irregular outlines and are much larger than the feldspars forming the groundmass of the porphyry. The latter is uncommonly poor in quartz. One might therefore suppose that these veins rich in quartz are segregations from the porphyry. In the following we are going to form acquaintance with strings of a rather similar composition, occurring in the porphyries of Sakaravaara and Tuolluvaara, which doubtless have such an origin. These strings are, however, more intimately connected with the rock containing them than those occurring at Luossavaara.

A similar breccia occurs in several other exposures, higher up the southern slope of the mountain, but a coherent zone does not exist. The tourmaline-bearing chlorite mass on the contrary does not seem to occur out of this southernmost exposure.

The quartz-porphyry following immediately east of this breccia, or, where the latter is wanting, immediately east of the ore, is unaltered and contains no magnetite dikes, but everywhere numerous inclusions of ore. These sometimes make up more than half the volume of the rock. Part of the fragments has probably been assimilated by the porphyry. The local abundance of relatively large crystals of magnetite and apatite in the groundmass of porphyry larded with ore fragments can scarcely be explained in any other way.

On the summit this contact is sharply defined.

About 650 meters north of the summit, in the western half of the

claim of Gabriella, there is an exposure of porphyry. The rock is rather similar to the quartz-porphyry, but its groundmass is highly altered, to chlorite etc. It contains schlieren of magnetite, some of which are a few dm wide. This is perhaps corresponding to the ore level.

Summary and conclusions. The characters of the foot wall contact show that the ore is younger than the main mass of the syenitic rocks. This appears very distinctly on northern Kiirunavaara, where we found the following periods: 1. »Older» syenite-porphyries, 2. dikes of syenite-porphyry and sheets connected with them, 3. the ore, 4. dikes of syenite-porphyry, in their composition almost identical with No. 2. This great resemblance between the dike rocks seems to denote that the eruption of all these rocks and the formation of the ore must have taken place in a very short time. The ore has caused an amphibolization of the wall rock, this metamorphism is sometimes rather intense but has befallen only the parts lying in the most immediate neighbourhood of the contact. That it is not of more recent date appears from the fact, that it in such an inconsiderable degree has befallen the porphyry dikes younger than the ore. Even the formation of the ore breccia must practically be contemporaneous with that of the main ore body. This is shown by its intimate connection with the latter, and by the circumstance that even the breccia is followed by amphibolization.

The hanging wall contact is less instructive. Farthest south we find phenomena indicating that the ore is younger than the quartz-porphyry. Some features of northern Kiirunavaara and Luossavaara favour such a view, but the occurrence of the numerous inclusions of ore, originating from a petrographically quite similar ore deposit, are against it. The writer is therefore inclined to assume that the ore and its hanging wall rock are almost contemporaneous in their formation.

The occurrence of tourmaline in different places on the contact is worthy of observation. It is scarcely possible that its formation is a phenomenon of a much later age, as just these tourmaline-bearing chlorite masses with quartz and some other minerals are limited to these contacts.

Mineral veins in the ores.

Among the mineral veins occurring in the ore those of copper ore ought to be considered before others. Such a one is exposed in the open cut of Professorn, in the foot wall rock; it is not known whether it has

run further into the ore. The vein is only some cm wide. The chief mineral is bornite, which to a great extent has been altered to chrysocolla. Moreover there are often seen white quartz and small black tourmalines. The microscopic examination shows other minerals too. In the chrysocolla mass there are single laminated plagioclases, some of which reach a size of a few mm, their refraction being inconsiderably higher than that of the Canada balsam. A greenish brown, strongly pleochroic mica is seen in abundance as phenocrysts having a size of some tenths of a millimeter, with marked, nearly always curved cleavage cracks. Apatite and rutile also occur.

In Geologen there is also an occurrence of copper ore, but its relations to the iron ore are unknown. The writer has found it as but a few pieces having a diameter of some dm, lying among ore from a nowadays inaccessible shaft. Even here the copper mineral is bornite. The microscopic examination shows a mixture of bornite and hornblende in about the same quantities. The hornblende is pale green and occurs in prisms reaching a length of up to 1,5 mm. It is sometimes idiomorphic, but in other cases the bornite penetrates along its cleavage cracks. It is accordingly probable that the hornblende has crystallized somewhat before the bornite. The ophitic structure indicates that this copper ore is a magmatic product.

Some years ago a very interesting copper vein was exposed in Vaktmästaren. The writer never had an opportunity of seeing it. A specimen is described by STUTZER [62] who has found the following minerals: plagioclase, augite, biotite, bornite, chalcopyrite, and some apatite, tourmaline and garnet. The copper minerals have crystallized last, and have corroded the other minerals.

Drusy quartz veins are not seldom seen, but never reach very large dimensions. Calcite occurs also as a veinforming mineral, sometimes together with quartz and containing crystals of pyrite and grains of chalcopyrite. Pyrite sometimes coats the jointing planes, but is as a rule rare.

Quartz porphyry.

Exposures.

The quartz-porphyry is on the whole better exposed than the syenite rocks. There are numerous outcrops of it on the eastern slope of Kiirunavaara (not to the south of Professorn, however), besides it is exposed owing to mining operations partly in some adits (Professorn, Landshöfdingen, Bergmästaren), partly in the open cuts in the most northerly parts of the mountain. The group of outcrops never extends more than about 800 meters to the east of the ore, further to the east there are only a few outcrops, among them a group located more to the south than any of the above mentioned ones (southeast of Jägmästaren). The western slope of mount Haukivaara, where Kiruna is now situated, was originally uncovered to a large extent, and on account of various works, the opening of a quarry, the building of roads, and the digging of wells and ditches, the number of exposures has been considerably increased.

The natural outcrops continue so far towards the north in the direction of Luossavaara that the entirely covered and unknown zone immediately south of this mountain has a width of only 200 to 700 meters, being thus considerably smaller than the distance between the exposures of syenitic rocks on both sides of lake Luossajärvi. On mount Luossavaara there are numerous outcrops, the rock being moreover exposed in numerous excavations made for the examination of the ore. Northeast of this mountain, the intervening covered area is only about 400 meters, even here much less than is the case with the syenitic rocks. Between Luossavaara and lake Nokutusjärvi there are several outcrops, the most northerly ones situated about 250 meters south of the lake. After this the quartz-porphyry is not exposed until on Hopukka. This rather unimportant occurence

is treated on p. 188. Further off there is a narrow band on the eastern slope of Välivaara.

Between the syenitic rocks and the quartz-porphyry there are the great ore bodies of Kiirunavaara and Luossavaara. Within the regions where the two kinds of porphyry are immediately adjacent, the contact is always covered with moraine. There are, however, a little south of Nokutusjärvi outcrops of the different porphyries only some meters from one another. The quartz-porphyry does not seem to have affected the older rocks by any kind of contact metamorphism.

Macroscopic characters.

The quartz-porphyry is less variable than the syenitic rocks, and the different types which can be distinguished occur on the whole rather separated from one another.

Within a lenticular area on Luossavaara, elongated in the general direction of strike, there occurs an agglomeratic phase which is sometimes like a tuff-breccia. Similar phenomena occur also more towards the northeast, at the border of the syenitic rocks somewhat to the south of Nokutusjärvi.

The quartz-porphyry shows extensive but irregular jointing.

With the exception of the agglomeratic phases and some strongly pressed zones, the quartz-porphyry is always a perfectly massive rock, porphyritic, with feldspar phenocrysts (phenocrysts of quartz never occur) in a very fine-grained or most often dense groundmass, which has no visible nodules of any kind (except only a small area at Professorn, where nodule-like aggregates of magnetite occur). It may very conveniently be divided into the following four types, which in their most characteristic forms are rather dissimilar but show gradual transitions to one another.

Type 1. Rich in feldspar phenocrysts which partly have the same shape as those of the syenitic dike-porphyries and partly are smaller and rectangular. The colour is generally red in various shades, the size of the rectangular ones is 1 to 5 mm, while the others reach a diameter of up to 15 mm. Phenocrysts of other minerals are not seen. The groundmass is dense, of a grayish red, more seldom brownish red colour. A flow-structure sometimes appears by the alternation between dark and light bands.

Very subordinately there occurs a still more distinctly dense phase, almost free from macroscopically visible phenocrysts. It occurs in schlieren which are often but a few cm wide but nevertheless sometimes reach a length of several meters, running almost straightly and parallel to the general direction of strike. They often show alternating bands of a dark gray or reddish colour. In one place there has also been observed a little schliere with small red feldspar phenocrysts in a dark groundmass; its border towards the normal porphyry is rather abrupt.

This type (1) is beyond comparison the most common one, it is predominant on Kiirunavaara, on Porfyrberget (including the municipality), and occurs on Luossavaara and north of this mountain towards Nokutusjärvi partly in the westernmost parts of the porphyry, partly further eastwards, the groundmass, however, having then a more gray colour and the phenocrysts often being purely white. Furthest east in Kiruna the colour is intensely red, the feldspar phenocrysts small and rectangular.

Type 2. This type contains feldspar phenocrysts in perhaps still greater abundance than the precedent one. They are generally similar to the first kind belonging to this type and reach a diameter of about 10 mm on an average. They are of a purely white colour. The groundmass is dense and whitish to blackish gray in colour. There also occur streaks and patches of a green fibrous hornblende, which is rather abundant in places and sometimes forms veinlets which quite interweave the rock. In a few cases veins of dense magnetite of hardly a finger's breadth have also been seen.

This type can scarcely be distinguished with certainty from the syenitic dike-porphyries. It occurs only on Kiirunavaara, where it extends immediately east of the ore from Kapten to the south and northwards to southern Statsrådet, with a width scarcely reaching more than 100 meters anywhere. Between Vaktmästaren and Luossajärvi there occurs a rather similar type.

No contact between this type and the precedent one has been found, on the contrary there occur phases which seem to hold an intermediate position, indicating the occurrence of transitions. As the second type on account of its macroscopic characters and, as will be shown later on, even under the microscope appears to be something between the preceding one and the syenitic dike-porphyries, there is nothing very astonishing in the writer's not having been able to find out whether it is a phase of the

former or geologically independent of it and more intimately associated with the latter.

Type 3. This type differs from the first one by having smaller feldspar phenocrysts and a fine-grained, grayish red groundmass, in which tiny, rusty spots often appear. Its distribution is very limited, it has been found only in a ditch along the railway line about 1250 meters southeast of the south end of lake Luossajärvi.

Type 4. Compared to the precedent ones, this type is characterized by the colour of the groundmass, which is bluish gray, blackish gray or almost pure black. The phenocrysts are generally quite similar to those of type 1. Occasionally they are, however, few and small.

This type occurs in Kiruna, mingled with the prevalent type 1, and appears now as schlieren of various sizes, now as fragmental, sinuous bodies generally having a length of some dm and always elongated in the general direction of strike. On Luossavaara it is commonly found as schlieren in type 1, on both sides of the agglomeratic zone.

Microscopic characters.

Type 1. Feldspar phenocrysts. The feldspar phenocrysts may be divided into two types, between which successive transitions occur. One type consists of single individuals (including twins according to the common laws and microperthitic intergrowths) or of phenocrysts composed of several single individuals as in the syenitic dike-porphyries, but as a rule not so complicated as in them. Rhombic sections, showing that (110) and $(1\bar{1}0)$ are the dominant planes, occur rather often, but broadly rectangular sections are more common, indicating a thickly tabular habit parallel to (010). The idiomorphism in generally good, though the angles are often somewhat blunted.

These phenocrysts are most often microperthitic, the potash component as a rule being rather subordinate; only in a few places, as in the lowland northeast of Statsrådet, it constitutes a considerable part of the microperthite individual. The potash-feldspar occurs in thin stripes, generally similar to those of the phenocrysts of the syenitic dike-porphyries. The plagioclase component is generally finely twinned according to the albite law, sometimes »striped» and sometimes finely cross-twinned. It must evidently be oligoclase-albite or albite, as also appears from the analyses. Especially when cross-twinned it is sometimes very similar to soda-microcline.

The other phenocryst type nearly always occurs as single crystals or simple Mannebach twins and shows broadly rectangular sections, it is »striped» plagioclase without any perthitic intergrowths. A cleavage system running at right angles to the albite lamellæ is often seen. The refraction is considerably lower than that of the Canada balsam, thus it must be albite. Fragments of crystals are also often found.

The first-mentioned rather complicated type of phenocryst is the most common one on Kiirunavaara and Luossavaara, the rhombic habit, however,

being typical on the former mountain only; the latter type appears to be very common in the eastern parts of the district, for instance on Porfyrberget.

Primary inclusions are seldom seen in the phenocrysts; they generally consist of small crystals of magnetite or zircon, fibrous hornblende (secondary?) occurs now and then. Neither are secondary products common, small flakes of muscovite and a little calcite sometimes develop; titanite is seldom seen, occuring in irregularly branching grains. In one place a phenocryst is partly replaced, some quartz in rounded grains and small plates of greenish brown biotite having been formed during the process.

The *groundmass* is made up of feldspar and quartz, some magnetite and some other minerals in very small quantities. The two principal constituents occur in about similar quantities, the feldspar being, however, generally somewhat

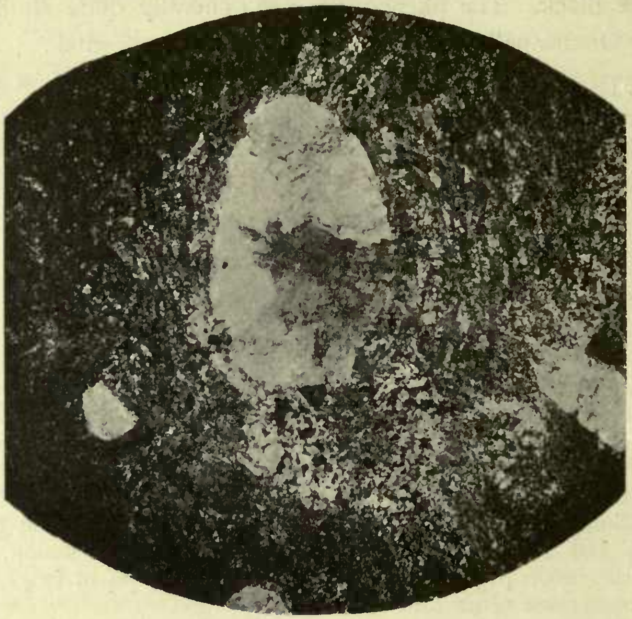

Fig. 45. Quartz-porphyry, type 1, Kiirunavaara (analysis No. XIV). Nic. +. Magn. 14 times. Microperthite phenocrysts in a micropoikilitic groundmass, which shows fluidal structure developed by the parallel elongation of the quartz »sponges».

predominant. The small size of the feldspars and the presence of pigment renders the determination of their optical properties very difficult. It appears, however, from the analyses that they to a large extent must be potash-feldspar.

The structure is now microgranitic, now micropoikilitic. In the former case both minerals occur in the shape of grains with a diameter of some hundredths of a millimeter or less and with complicated outlines towards one another. In the latter case, when examined between crossed nicols, the groundmass is seen to be divided into areas with a diameter of some tenths of a millimeter, within which at least one component is optically homogeneous. These areas are now angular or rounded, now much elongated, bending about the phenocrysts and causing the appearance of a marked flow structure.

A close examination of such an area shows that the quartz is always at least nearly optically homogeneous. Such is very evidently the case when this mineral occurs in the shape of fine, somewhat divergent rays, but it appears also in the more common shape, when it has the character of a sponge including irregular feldspar grains. The feldspar particles within such an area sometimes seem to be orientated all in the same way; in such cases the structure must be called granophyric, while it generally has a distinct poikilitic character.[1] Transitions from this structural form to the microgranitic one occur.

Irregular sphærulites sometimes occur. The writer has not been able to determine their nature, but they are perhaps composed of feldspar and quartz. Between crossed nicols there appear in at least one case two dark crosses having a common centre, the arms of one of them are parallel to the directions of vibration of the nicols, the arms of the other one form a very small angle with it. These characters seem to denote that the sphærulite may consist of two different substances (quartz and feldspar?).

Hornblende occurs in some slides, in fibrous individuals having a length of some tenths of a millimeter; it alters to chlorite. Apatite in short prisms is almost as rare a constituent. The titanite also occurs very sparingly and always without idiomorphism. Zircon is rather common and has the shape of thick, well idiomorphic crystals with prismatic and pyramidal faces; they generally reach a length of 0,1 to 0,2 mm. They are often surrounded by a small zone of red pigment. Calcite occurs sparingly in irregular grains; in one slide there are seen a few idiomorphic crystals of ferruginous carbonate enclosed in a feldspar phenocryst.

The magnetite is the most important dark constituent of the quartz-porphyry; its quantity generally amounts to some per cent of the rock. It occurs in idiomorphic crystals, generally having a diameter of less than 0,1 mm, but sometimes in angular lumps of up to 0,4 mm in diameter. It often defines a flow-structure in the groundmass.

In the groundmass there often occur areas which are somewhat coarser than the bulk of it and sometimes also have a different composition. These bodies are often elongated, reaching a length of 1 or a few mm, sometimes more, and are often fluidally arranged; they are very seldom rounded. The outline towards the normal groundmass is now very badly defined, now quite sharp. The mineral constituents are quartz (generally predominant), magnetite, biotite, feldspar, sometimes also others, as zircon and apatite. The quartz generally occurs in isometric grains, about 0,1 mm in size, with somewhat rounded outlines. The feldspar occurs in irregular individuals of about the same size as the quartz grains. The magnetite is idiomorphic, the crystals often reaching a length of 0,15 to 0,20 mm or more; the greenish brown biotite forms small plates. There also appear streaks consisting exclusively of magnetite and biotite.

At least the greatest part of these streaks seems to be of primary origin. Schlieric aggregation of the quartz in groundmasses rich in this mineral is a very common phenomenon; these streaks may be changed by later influences but in their original character they are of an altogether primary origin.[2] Their being arranged parallel to the flow structure caused by the parallel extension of the micropoikilitic fields appears to the writer to favour this opinion. The shape of the quartz grains may perhaps be ascribed to recrystallization due to pressure.

[1] The writer has in his preliminary report on the apatite dikes called it »quartz globulaire» on account of the analogy to groundmasses described under this name, but that seems to be too wide an extension of the sense of the word.

[2] See for instance ROSENBUSCH (II p. 752).

According to the opinion of the writer, the streaks occurring in the quartz-porphyry are most equal to the nodules of the syenitic rocks. This opinion is also authorized by those in many respects similar streaks occuring in the quartz-porphyry rocks of Sakaravaara and Tuolluvaara.

Still more evident is the primary nature of streaks of quite the same shape and size as those described above, but consisting of quartz and feldspar in about the same proportions as in the normal groundmass. They differ from the latter by their coarser grain, which is only a little finer than that of type 3, and by their structure, which is very similar to that of the last mentioned type. It is accordingly granophyric but not very complicated, the feldspar particles included in a quartz individual are generally scarce and show, just as the points of the

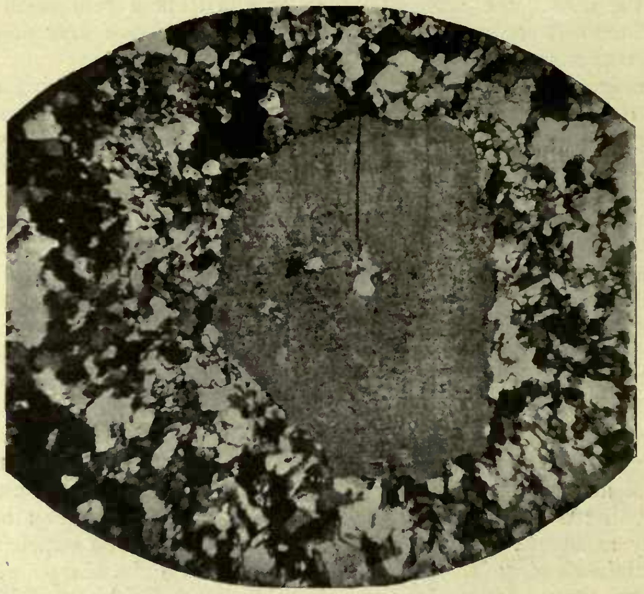

Fig. 46. Quartz-porphyry, type 3, at the railway south of Kiruna. Nic. +. Magn. 35 times. »Striped» albite phenocryst in a groundmass of albite and quartz in a slightly complicated granophyric intergrowth.

same mineral inserted in them, thinly rectangular sections. This granophyric intergrowth shows very distinct transitions to the form common in the normal groundmass.

Type 2. Its *feldspar phenocrysts* are quite similar to the kind described p. 127, they are perhaps only more closely akin to those of the syenitic dike-porphyries.

Augite of the same species as that occurring in the syenitic rocks and in the ore occurs partly as skeleton phenocrysts with a length of about 1 mm, partly as small grains. The greatest part of it is transformed into uralite having the usual optical properties of the hornblende of the Kiruna rocks. But this hornblende has probably also to some extent replaced feldspar, as also seems to be the case in the syenitic rocks. Lumps of epidote have evidently originated from the green silicates.

The *groundmass* contains as much quartz as that of the precedent type, the structure is microgranitic. Small crystals of magnetite occur.

Type 3. The *feldspar phenocrysts* are single or compound, they consist of plagioclase (albite), finely »striped» or cross-twinned, sometimes with small quantities of potash-feldspar in microperthitic intergrowth. They alter to muscovite and green chlorite.[1] The idiomorphism is partly rather good, but many phenocrysts are by a granophyric rim connected with the surrounding groundmass.

The *groundmass* consists of feldspar and quartz in about equal quantities. The greatest part of the feldspar is evidently plagioclase, it shows »striped» lamination; among the not laminated grains some of orthoclase may perhaps be found. The structure must be called granophyric, but is little complicated, it reminds us most of the intergrowth of feldspar and quartz in the Kiirunavaara syenite. It seems to be the rule that the granophyric intergrowth is less complicated when the feldspar consists chiefly of plagioclase than when it is a potash-feldspar.

The individuals of feldspar and quartz reach some tenths of a millimeter in diameter. Besides there also occur zircon, magnetite, muscovite and chlorite, all of them in very small quantities, and rather numerous well idiomorphic crystals of ferruginous carbonate reaching a diameter of up to 0,8 mm. The rusty spots, which are even macroscopically visible, are evidently caused by the weathering of this mineral.

Type 4. The *feldspar phenocrysts* are similar to those of type 1, but they are generally rather uncomplicated. They are now sharply idiomorphic, now highly corroded, showing inclusions of groundmass appearing to be sections of »corrosion bays».

The *groundmass* is very fine-grained, now irregularly micropoikilitic, now sphærulitic, the sphærulites reaching a diameter of some tenths of a millimeter. The dark colour is caused by magnetite which is always very abundant, being now very finely distributed as a dark pigment and now occurring in small grains arranged in rows, the grouping of which resembles the skeleton structure of the Hopukka rocks, described p. 76. In the feldspar phenocrysts magnetite is seen only in the inclusions of groundmass. In the »corrosion bays» and in corners between the phenocrysts it is sometimes accumulated in such a quantity that the groundmass is nearly pure ore. But small patches almost free from magnetite also often occur. The quantity of the mineral surely often amounts to about 15 per cent of the rock, being, however, generally less than 10 per cent. A fluidal arrangement of the magnetite is common. On Luossavaara rather much biotite also occurs in this type. Streaks analogous to those of type 1 are sometimes seen.

Chemical characters.

There are four analyses of the quartz-porphyry, an old one (XIV) quoted by Lundbohm and Bäckström, and three made for this work.

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[1] The chlorite is perhaps developed from inclusions of biotite. See p. 196.

	XIII	XIII a	XIII b	XIV	XIV a	XIV b	XV	XV a	XV b	XVI	XVI a	XVI b
SiO_2 . .	69.08	1144	76.10	71.30	1180	77.24	70.81	1172	77.75	66.46	1100	73.63
Al_2O_3 . .	12.75	125	8.30	13.53	132	8.66	14.31	140	9.29	15.08	148	9.91
Fe_2O_3 . .	5.84	37		2.33	15		2.06	13		3.09	19	
FeO . .	2.16	30	6.88	1.75	24	3.59	0.84	12	2.51	1.33	19	3.88
MnO . .	0.02			0.07	1		0.03			0.04	1	
MgO . .	0.50	12	0.82	0.70	17	1.13	0.67	17	1.10	0.70	18	1.21
CaO . .	0.28	5	0.33	0.67	12	0,78	0.85	15	1.01	1.76	31	2.08
Na_2O . .	3.97	63	4.25	5.77	93	6.07	6.22	100	6.63	6.40	103	6.89
K_2O . .	4.39	47	3.09	3.02	32	2.09	2.15	23	1.51	2.74	29	1.94
H_2O+ .	0.78	43		0.56	31		0.55	31		0.65	36	
CO_2 . .							0.88	20		1.22	28	
TiO_2 . .	0.27	3	0.22	0.51	6	0.42	0.25	3	0.21	0.49	6	0.40
P_2O_5 . .	0.02			0.03			0.06			0.07	1	
S . . .	0.02						0.02			0.04	1	
Sum	100.08			100.24			99.70			100.07		
H_2O- .	0.05			n. d.			0.09			0.08		

XIII. Red porphyry from the claim of Amos, 280 meters east of the ore between Kapten and Pojken, Kiirunavaara (K. SCHRÖDER analyst.)

XIII a. The molecular proportions of XIII, multipl. by 1000.

XIII b. As above, calculated on a sum of 100, free from H_2O and CO_2, all Fe as FeO.

XIV. Red porphyry, Kiirunavaara, some hundred meters south of XIII and somewhat nearer the ore body (H. SANTESSON analyst).

XIV a. See XIII a.

XIV b. See XIII b.

XV. Red porphyry, about 5 meters from the ore, summit of Luossavaara (G. NYBLOM analyst).

XV a. See XIII a.

XV b. See XIII b.

XVI. Porphyry with bluish gray groundmass, east of the agglomeratic zone, Luossavaara (G. NYBLOM analyst).

XVI a. See XIII a.

XVI b. See XIII b.

The calculation of the analyses gives the following results:

American system.

No. XIII. *Norm.*

Quartz	SiO_2	27.91	Q 27.91		Sal 89.78
Orthoclase . . .	$K_2O . Al_2O_3 . 6 SiO_2$	26.27			
Albite	$Na_2O . Al_2O_3 . 6 SiO_2$	33.19	F 60.85		
Anorthite . . .	$CaO . Al_2O_3 . 2 SiO$	1.39			
Corundum . . .	Al_2O_3	1.02	C 1.02		
Hypersthene . .	$MgO . SiO_2$	1.21	P 1.21		Fem 9.52
Magnetite . . .	$FeO . Fe_2O_3$	6.26			
Hematite . . .	Fe_2O_3	1.60	M 8.31		
Ilmenite	$FeO . TiO_2$	0.45			

Sum 99.30 + H_2O etc. = 100.12

Class 1 Persalane, Subclass 1 Persalone, Order 4 Britannare, Rang 1 Liparase, Subrang 3 *Liparose.*

No. XIV. *Norm.*

Quartz	SiO_2		23.56	Q	23.56	Sal 92.39
Orthoclase . . .	$K_2O . Al_2O_3 . 6 SiO_2$		17.89	F	68.83	
Albite	$Na_2O . Al_2O_3 . 6 SiO_2$		48.99			
Anorthite . . .	$CaO . Al_2O_3 . 2 SiO_2$		1.95			
Diopside . . .	$CaO . SiO_2$	0.58	1.08	P	2.82	Fem 7.21
	$MgO . SiO_2$	0.50				
Hypersthene . .	$MgO . SiO_2$	1.21	1.74			
	$FeO . SiO_2$	0.53				
Magnetite . . .	$FeO . Fe_2O_3$		3.48	M	4.39	
Ilmenite	$FeO . TiO_2$		0.91			

Sum 99.60 + H_2O etc. = 100.19

Class 1 Persalane, Subclass 1 Persalone, Order 4 Britannare, Rang 1 Liparase, Subrang 4 *Kallerudose.*

No. XV. *Norm.*

Quartz	SiO_2	23.38	Q	23.38	Sal 93.38
Orthoclase . . .	$K_2O . Al_2O_3 . 6 SiO_2$	12.86	F	69.80	
Albite	$Na_2O . Al_2O_3 . 6 SiO_2$	52.68			
Anorthite . . .	$CaO . Al_2O_3 . 2 SiO_2$	4.26			
Corundum . . .	Al_2O_3	0.20	C	0.20	
Hypersthene . .	$MgO . SiO_2$	1.70	P	1.70	Fem 4.88
Magnetite . . .	$FeO . Fe_2O_3$	2.09	M	3.18	
Hematite . . .	Fe_2O_3	0.64			
Ilmenite	$FeO . TiO_2$	0.45			

Sum 98.26 + H_2O, CO_2 etc. = 99.77

Class 1 Persalane, Subclass 1 Persalone, Order 4 Britannare, Rang 1 Liparase, Subrang 4 *Kallerudose.*

No. XVI. *Norm.*

Quartz	SiO_2		14.68	Q	14.68	Sal 89.60
Orthoclase . . .	$K_2O . Al_2O_3 . 6 SiO_2$		16.21	F	7492.	
Albite	$Na_2O . Al_2O_3 . 6 SiO_2$		54.25			
Anorthite . . .	$CaO . Al_2O_3 . 2 SiO_2$		4.46			
Diopside . . .	$CaO . SiO_2$	1.75	3.26	P	3.56	Fem 8.55
	$MgO . SiO_2$	1.51				
Hypersthene . .	$MgO . SiO_2$		0.30			
Magnetite . . .	$FeO . Fe_2O_3$		3.28	M	4.99	
Hematite . . .	Fe_2O_3		0.80			
Ilmenite	$FeO . TiO_2$		0.91			

Sum 98.15 + H_2O, CO_2 etc. = 100.13

Class 1 Persalane, Subclass 1 Persalone, Order 4 Britannare, Rang 1 Liparase, Subrang 4 *Kallerudose.*

Osann's system.

	s	A	C	F	a	c	f	n	k
XIII . . .	76.32	7.34	0.96	7.07	10	1	9	5.8	1.44
XIV . . .	77.66	8.16	0.50	5.00	12	1	7	7.4	1.41
XV . . .	77.96	8.14	1.01	3.75	12.5	1.5	6	8.1	1.44
XVI . . .	74.03	8.83	1.08	6.09	11	1.5	7.5	7.8	1.25

No. XIII resembles the Syene granite most of all OSANN's types. The formula of this type is

$$s_{77.5} \quad a_{10} \quad c_1 \quad f_9$$

The three others are not very similar to any type. It must be observed that the high C value of No. XIII is composed of $0{,}33$ CaO and $0{,}63$ MgO, consequently it does not express the anorthite percentage of the rock.

A comparison between the chemical characters of the quartz-porphyry and those of the syenite and the »older» syenite-porphyries shows that the former has on an average about 10 per cent more SiO_2, while its content especially of CaO and MgO is very considerably lower than that of the other two rocks. The difference with regard to Fe_2O_3 and FeO is less striking, and in the quartz-porphyry the magnetite is the predominant dark mineral to at least as great an extent as in the »older» syenitic rocks.

With regard to the SiO_2 percentage, the quartz-porphyry is not very different from the dike syenite-porphyries, but on the other hand it differs very much from them by its higher content of iron oxides and lower content of CaO and MgO, a fact which appears mineralogically in the predominance of the magnetite over the pyroxene and amphibole minerals.

The alkalies vary about as much in the quartz-porphyry as in these two different syenitic groups, but there is no analysis of any quartz-porphyry phase corresponding to the albite rocks of the Nokutusjärvi region.

The mineral constituents show also, as well in their optical properties as in their crystal habits, a great resemblance to the same minerals in the syenitic group. I need only mention the microperthite, the albite, the augite, and the »rhombic» composed feldspar phenocrysts.

When the groundmass is microgranitic, the structure is very similar to that of the syenitic dike-porphyries; on the other hand the quartz-porphyry can never be mistaken for rocks of the older syenitic group.

Has any phase of the quartz-porphyry originally solidified as glass? Any remnants of perlitic structures or other features denoting that this

should have been the case are not to be found here any more than in the syenite-porphyries. But it is, however, rather probable, that some phases with very fine-grained, microgranitic groundmass with extremely finely distributed magnetite dust may be devitrified glassy rocks.

Agglomeratic zones.

The agglomeratic zone of Luossavaara is exposed for a length of about 300 meters and reaches a width of nearly 100 meters. The continuation to the south is covered, to the north we can see how it very suddenly narrows off and soon disappears altogether. On both sides it is surrounded by massive porphyry belonging to types 1 or 4 and containing fragments of ore to the west of the zone. As far as is known up to now, no such fragments occur east of it.

Within the zone there are seen several bands or elongated lenses of conglomeratic nature, consisting almost entirely of »pebbles», between these bands there is normal massive porphyry, generally containing isolated inclusions. This porphyry, which belongs now to one, now to the other of the types just mentioned, is often heterogeneous, schlieric and contains corroded phenocrysts, it is doubtless an igneous rock and not a recrystallized tuff. The fragments, both those more isolated in the porphyry and those making up the conglomeratic bands, are generally rounded, seldom angular; outcrops of the bands consisting almost entirely of such fragments with a very subordinate matrix therefore have the appearance of a normal conglomerate. It is true that no regular stratification appears, only a rude arrangement of the »pebbles» with their longer axes parallel to that of the agglomerate, i. e. to the general direction of strike.

The fragments vary in size from a few cm and up to more than 1 meter, most of them seem to reach about 1 dm or less. The matrix in the conglomeratic areas is often only a felt of biotite or chlorite, sometimes containing feldspar phenocrysts just as the porphyry. The outlines between the conglomerate and the surrounding porphyry are seldom sharply defined, the latter on the contrary is just at the contact very rich in enclosed fragments resembling the »pebbles» of the former. Some fragments do not show the usual rounded pebble form but are elongated with a tail, they seem to have been in a molten state when enclosed in the porphyry magma.

The nature of the fragments varies a good deal. Many belong to different varieties of the quartz-porphyry,[1] others, and these are the greater part, belong to the syenitic rocks. Pinkish, gray or brownish porphyritic feldspar rocks are most common, now and then containing nodules of magnetite or quartz. Magnetite-syenitic phases are also seen. Fragments of ore are very common in the porphyry even immediately west of the agglomeratic zone, but they are very rare within it. Further on there have been observed two quartzite pebbles, both well rounded, the larger one reaching a few dm in diameter and containing some pyrite and magnetite in considerable quantities.

The microscopic examination of the matrix gives but little information of its nature. It is already mentioned that the massive porphyry resembles the normal types; as well as the latter it sometimes also contains streaks of quartz and other minerals. The matrix of the conglomerate is in many respects similar to the porphyry, but the groundmass is to a great extent replaced by an aggregate of quartz and biotite, very probably of secondary origin. A considerable impregnation of calcite sometimes makes the determination of the groundmass still more difficult. In one slide there are seen feldspar phenocrysts and small pieces of groundmass lying in a matrix consisting chiefly of quartz in rounded grains.

There are, however, nowhere any signs indicating this matrix to be a true tuff, a mass of loose ashes or of crystal particles hardened under the influence of a later metamorphism. It is a true porphyry, now with an altogether normal groundmass, now with a groundmass consisting entirely of quartz grains or of quartz grains and biotite plates. It is of course rather difficult to determine how much of these characters may be of a primary nature, equal to the streaks rich in quartz occurring in the massive porphyry, and how much is caused by secondary processes.

The fragments of quartz-porphyry correspond even in their microscopic characters most nearly to type 1 and offer nothing of interest. They are not finer grained than the common porphyry, rather the contrary, which indicates that they are no lava bombs. It is remarkable that type 4, which is prevalent in the neighbourhood, is not found among the fragments.

The syenitic porphyries have albite phenocrysts in a groundmass generally consisting almost exclusively of the same feldspar and often containing nodules of feldspar and quartz or of calcite with rutile, some-

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[1] Type 1 is almost the only one represented, but there are also some fragments rather similar to type 3.

times also of magnetite. Calcite often impregnates the whole groundmass, sometimes occurring in large, very irregularly branching individuals.

The largest quartzite fragment consists of quartz and magnetite in about equal volumes, some pyrite, small quantities of biotite and probably also rutile. The quartz occurs in grains reaching a size of $0{,}1$ to $0{,}3$ mm in diameter and with uncomplicated outlines. The magnetite is equally distributed in the quartz mass, it occurs in sharply idiomorphic crystals reaching a diameter of some tenths of a millimeter. The pyrite occurs in an analogous manner, partly surrounded by magnetite. This fragment is doubtless the one of quartzite containing iron ore minerals mentioned by STUTZER [62], it is very conspicuous and, as far as I know, the only one of this kind in the agglomeratic zone. STUTZER is, however, very probably quite wrong in believing this fragment to originate from the Hauki complex. (See p. 249).

The agglomeratic zone between Luossavaara and Nokutusjärvi is also lenticular, its length is about 250 meters, the width amounts to nearly 100 meters. The zone is bordered on the east by quartz-porphyry with red groundmass and belonging to type 1, in the west the same rock is exposed in two places between the zone and the syenitic rocks but nowhere the width of this intervening space amounts to more than some 20 meters. For the rest the area between the agglomeratic zone and the normal porphyries is covered. The quartz-porphyry in the west has generally a grayer groundmass than that to the east of the zone, otherwise it is quite similar to it. In the very zone there are some outcrops of massive porphyry, which probably occurs in bands in the same way as on Luossavaara.

There are numerous outcrops in the zone, but the lichens covering them render an examination very difficult. Here, the character is as a rule rather that of a breccia than of a conglomerate, the fragments being generally more angular than in the zone on Luossavaara. Here and there are seen areas of porphyry with a groundmass consisting chiefly of biotite in small plates, the same type that we found as matrix in the other place, in these areas rather well rounded fragments are lying.

As far as the writer has been able to ascertain, the fragments belong exclusively to the syenitic group of rocks, and there are feldspar rocks of a gray or pinkish colour and magnetite-syenite-porphyries among them, all of them often containing nodules. Outcrops of the rock on the whole have the appearance of a syenitic porphyry, brecciated by the development of countless small biotite veins, but in other cases fragments of quite different rocks are lying close together.

The microscopic examination of a slide of the matrix mentioned above, which consists of feldspar phenocrysts in a groundmass rich in biotite, shows it to be quite similar to the kind from Luossavaara already described, viz. a quartz-porphyry, the groundmass of which to a great extent consists of quartz and biotite, both probably of secondary development. The syenitic fragments resemble the rocks occurring immediately west of the agglomeratic zone, at least as much as the fragments on Luossavaara do.

What is then the origin of these agglomerates? LUNDBOHM and BÄCKSTRÖM [42] regarded them as agglomeratic true tuffs, STUTZER on the other hand, who had probably only seen the zone on Luossavaara, points out [62], that the matrix is a somewhat altered quartz-porphyry and that the fragments are partly somewhat resorbed; he considers the phenomenon to be an eruptive breccia. According to the opinion of the writer, the characters of the more northerly lens indicate that it is a fragmental tuff of syenitic rocks, perhaps also to some extent the top parts of a very mighty outflow of syenitic lava, which have partly been overflowed by the quartz-porphyry mass, partly been cut by dikes coming from the same. The more southerly lens, viz. the one on Luossavaara, seems to be of an analogous origin; the fragmental syenitic material has perhaps been ejected by an explosion and mixed with the quartz-porphyry, marking the limit between two not quite contemporaneous outflows. These imagined explosions have probably not taken place until after the complete solidification of the syenitic rocks.

There is also an other alternative, which, however, on account of the mixture of altogether different kinds of rock, does not seem to the writer to be quite as probable as the above mentioned one. One might think that these masses of inclusions originate from a place where the quartz-porphyry has broken through such rocks and that they even after its extrusion have kept together and formed a fairly definite level. This is very likely also the view of STUTZER. A combination of these two alternatives is of course also possible. It is accordingly, as is often the case with volcanic phenomena in ancient rocks, rather difficult to give an exact explanation of the origin of these agglomeratic bodies, and it is surely most prudent not to found any very far-extending conclusions on our opinion of the matter.

Apatite dikes.

Small dikes of finely crystalline apatite occur, as has already been stated, in some places among the syenitic rocks, principally between Luossavaara and Nokutusjärvi. In the quartz-porphyry these phenomena appear in a much greater abundance and show more interesting characters.

The writer has already published a short report on these apatite dikes [14], the following description is somewhat more exhaustive. [1]

Distribution and mode of occurrence.

The apatite dikes occur in the neighbourhood of the eastern border of the quartz-porphyry mass; more to the west in it they occur very sparingly and only in the most northerly parts of the mass, between Luossavaara and Nokutusjärvi. Within this area they are most numerous and reach the largest dimensions. In a zone about 600 meters in length and about 100 meters in width from the eastern border of the quartz-porphyry and towards the west, in the claims of Simeon, Enok and Abel, the rock is quite brecciated by numerous, generally quite straight apatite dikes, as a rule varying in width between some cm and one or a few dm. In the porphyry between these dikes there occur more irregular veins of quartz and hematite in crystal plates. The largest apatite dike runs nearly west and east, its length amounts to about 40 meters, the width generally varies between $0{,}5$ and 1 meter, but amounts in places to 2 meters. Only some part of this width, however, is apatite, as the dike is filled with fragments of porphyry, from huge blocks down to single feldspar grains. Especially the larger fragments are sharply angular. The dike ends in a few short veinlets.

The dikes generally seem to follow the planes of weakness (jointing planes) of the porphyry, as appears from their being so very straight and from the sharply angular form of the enclosed fragments. They are only very seldom winding. The contacts with the wall rock and the enclosed fragments are as a rule sharply defined.

On Luossavaara the dikes are rather common, but only in the most eastern outcrops, their width is probably never more than 1 dm. Between Luossavaara and the small lake Matojärvi they are rather abundant, but

[1] The specimen of »Ringelerz» described by STUTZER [62] must originate from the apatite dikes and not, as he supposes, from the main ore of Luossavaara. (Compare 14.)

even there they occur only in the most easterly outcrops and are quite small.

On Porfyrberget there are numerous quite small veins in a zone located about 200 meters west of the eastern border of the quartz-porphyry. Further southwards the writer has not been able to find them in situ, which must be exclusively ascribed to the fact that the most easterly parts of the rock containing them, viz. the quartz-porphyry, there are covered with moraine and partly also with morasses. The ocurrence of nu-

Fig 47. Detail of the largest apatite dike, claim of Abel. Porphyry fragments in a matrix of pure apatite. The figures on the band mark centimeters.

merous morainic boulders of quartz-porphyry penetrated by small veins of apatite along the road from Kiruna to Tuolluvaara shows, however, that these phenomena occur all along the eastern border of the rock east of Kiirunavaara.

Macroscopic characters.

The chief constituent of the dikes is always the apatite, which is almost the only macroscopically visible mineral in many dikes between Luossavaara and Nokutusjärvi, as for instance the above mentioned large one, and in nearly all dikes further south. Other minerals visible to the naked eye are magnetite and hematite, which are very common, tourmaline, and very seldom hornblende.

The apatite is finely crystalline and quite similar to that of the

great ore bodies. A coarser grained structure sometimes occurs, there is for instance a little vein in which the apatite individuals reach an average length of about 5 cm. Porphyritic structure occurs just as in the ore bodies, the phenocrysts sometimes reaching a length of several cm, while the individuals of the groundmass are not even 1 mm long. Drusy »pockets» are often seen; they are sometimes much elongated parallel to the borders of the dike, their width is seldom more than one or two cm. The crystals lying close to these cavities are generally bigger than the other ones. The apatite is always white or pinkish in colour.

A determination of the chlorine percentage made by N. PIHLBLAD gives 0,16 per cent Cl. Accordingly the apatite is fluorine-apatite as that of the ores.

The magnetite is generally finely crystalline, the same is the case with the hematite. These two minerals seem to occur in about equal abundance and mixed up with one another, the hematite is probably mostly of secondary origin (martite). Some dikes are so rich in these iron minerals, that one might call them ore. The ore minerals are sometimes equally distributed over the whole width of a dike, but generally they are concentrated in more or less strongly marked streaks running parallel to its borders. In this way the dikes often get a beautiful striped appearance and are very similar to the »stratified ore» of Kiirunavaara; a very distinct flow-structure also occurs. Both these phenomena are seen in figs. 48 and 49. In the latter is seen how a zone rich in ore minerals bends towards the place from where the dike sends out an apophysis. The ore minerals are sometimes concentrated in schlieric arranged lenses in the apatite mass or occur in coarsely crystalline lumps, one or a few cm in size, which are present both in rather wide dikes and in very tiny ones.

Angular fragments of apatite containing ore minerals in fluidal bands and lying in a matrix of pure apatite are often seen in the wide dikes.

The tourmaline is pitch black and occurs in prismatic crystals having a length of about 1 mm. They are often concentrated in streaks running parallel to the borders of the dikes or around enclosed fragments of the country rock. The tourmaline occurs principally in the claim of Abel, where it is rather abundant in a few small dikes. There also occur veins with a width of only about 1 cm, consisting exclusively of this mineral which is also sometimes found as a very thin coating on the jointing, planes of the porphyry. Among the dikes in erratic boulders along the road to Tuolluvaara there also are some rather rich in tourmaline.

Hornblende has as yet been observed only in a single dike just north

of Luossavaara. It occurs in columnar crystals a few mm long and of a green colour. The dike is very rich in finely distributed hematite.

The quartz-hematite veins are more irregular than the apatite dikes. The width is seldom more than 1 dm, generally much less. These veins often occur very evidently as apophyses of the apatite dikes; one may sometimes find an apophysis, which close to the apatite dike consists of

Fig. 48. Apatite dike rich in magnetite, shows banding and flow-structure. Claim of Abel. (The hammer lies on porphyry).

the same material as the latter, but is further off made up of quartz and hematite. A drusy mass of these two minerals sometimes fills the middle of an apatite veinlet. Finely crystalline hematite also occurs separately, filling extremely thin fissures in the porphyries.

Microscopic characters.

Mineral constituents. Beside the minerals mentioned above, the following ones enter as primary constituents into the apatite dikes: feldspar, quartz, zircon, muscovite, pyrite, orthite, biotite and titanite.

The apatite is in its optical properties and crystal habit quite similar to that of the great ore bodies, and contains the same acicular inclusions and plates of red hematite.

The tourmaline is strongly pleochroic: O = olive brown or deep blue, E = pinkish; absorption O > E. Zonal structure sometimes occurs, the central parts of the crystals being then blue, surrounded by an olive brown ring.

The hornblende shows the same pleochroism as that of the syenitic rocks and the ore, the extinction angle $\mathfrak{c}:c$ is at least 20°.

The feldspar is evidently mostly pure albite, it is limpid and shows a »striped» lamination, the extinction in sections cut nearly parallel to (010) varies between 9° and 18°. Cross-twinning sometimes occur, but even such individuals seem to be albite. The fragments of phenocrysts from the wall rock, which are often enclosed in the apatite mass, must be carefully distinguished from this primary feldspar. They contain red pigment, and small parts of groundmass often adhere to them.

The biotite is strongly pleochroic in brownish yellow shades.

The orthite is with regard to its optical properties similar to the one occurring in the syenitic rocks and their apatite dikes. The titanite is of no special interest.

Fig. 49. Apatite dike, claim of Abel. Shows flow-structure.
(The compass lies on porphyry.)

The writer must emphasize the fact that the pyrite, orthite and titanite are all very rare, the hornblende is seen in one dike only, the same is the case with the biotite. The feldspar has also a very limited distribution, while the quartz is seen somewhat more often.

The structure. The apatite mass is in its structural features quite similar to the bodies of the same mineral occurring in the ores of Kiirunavaara and Luossavaara. The shape and size of the individuals are quite the same as there. Trachytoidal flow-structure is sometimes seen, bending about porphyry fragments or crystals of hornblende or tourmaline. Radial arrangement also occurs, sometimes amounting to the development of regular sphærulitic groups.

When the dike mass consists of apatite and a great quantity of magnetite (or martite) the structure is the one commonly seen in such mixtures in the ore bodies; the ore minerals occur in single crystals or aggregates of crystals, often elongated in the same direction as the apatite grains. Very often they form jagged, irregular little lumps.

The feldspar appears in angular, often broadly rectangular sections, showing a tendency to idiomorphic development towards the apatite, which it, how-

ever, never reaches. It is generally somewhat larger than the apatites and often encloses small crystals of this mineral. It is also seen that an apatite sphærulite has partly been checked in its development by an adjacent feldspar. It is evident that these two minerals have crystallized almost at the same time.

The quartz often occurs in grains having a tendency to idiomorphic development but squeezed in between the apatite individuals. More often it forms a mesostasis, enclosing numerous apatite crystals. Sometimes it has an undulatory extinction, but in other dikes it is quite intact.

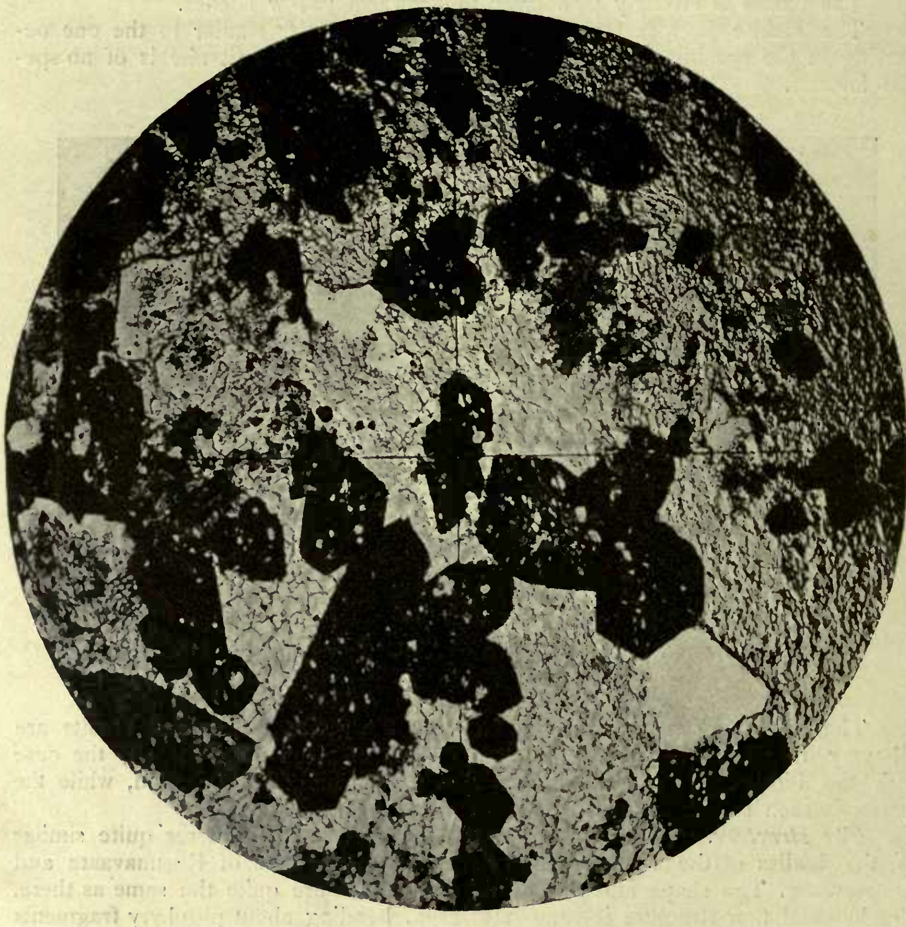

Fig. 50. Tourmaline in apatite, claim of Abel. Ord. light. Magn. 26 times. (The light spot below to the right is a hole in the apatite mass).

The tourmaline occurs in crystals having a length of 0,5 to 2,5 mm, generally sharply idiomorphic but sometimes so closely agglomerated that they have checked each other's development. The crystals are poikilitically larded with inclusions of apatite, generally somewhat elongated and lying in different directions. See fig. 50. A transitory form to granophyric intergrowth is developed by adjacent inclusions having the same optical orientation, sometimes there also

occurs a similar intergrowth of tourmaline and quartz, and small idiomorphic tourmaline crystals are often included in large prisms of the same mineral. Angular lumps of magnetite are also often included in the tourmaline.

The zircon occurs in the same manner as in the apatite masses of the Kiirunavaara ore, it is scarcely missing in any slide. It is seldom idiomorphic, but is very often enclosed in apatite.

Small plates of red hematite are often seen, they occur in the same way as in the ores.

The hornblende forms columnar crystals with a length of up to some mm, but shows no terminal faces. It occurs in a dike containing neither feldspar, nor tourmaline, nor quartz, but rather much orthite. This mineral forms irregular individuals with rounded outlines, reaching a diameter of up to 1 mm. The titanite is present in the same dike as the hornblende, as a coating enclosing crystals of apatite.

Muscovite in small idiomorphic plates is often seen, single or associated with tourmaline it often forms a ring around fragments of porphyry.

Chlorite is sometimes present in very small quantities. Otherwise there are scarcely any secondary products.

The contacts with the wall rock and with the enclosed fragments of the same are generally sharply defined even under the microscope. In the immediate neighbourhood of the contact there sometimes occurs a coarser grained zone in the groundmass of the rock, about a few mm wide; whether this structure is of primary origin or caused by contact metamorphism from the dike is difficult to settle. The rock contains red pigment in abundance, which generally appears to lie between the mineral individuals of the groundmass. Near the dikes there also appear in it numerous individuals of zircon and of apatite and other dike minerals, around these, especially around the zircon, the red pigment has gathered. There also occur spots of limpid albite, apatite, tourmaline, hematite, quartz and zircon, some pigment being often found between them. Tourmaline and quartz also occur together, in part replacing a feldspar phenocryst of the porphyry; the former is also present in the groundmass, the outline is sometimes much curved, somewhat resembling »corrosion bays». Orthite in rounded, skeleton individuals sometimes occurs in the porphyry close to the contact.

Comparison to the great ore bodies.

As has been stated several times above, the apatite dikes show very obvious resemblances to the phases of the ore bodies of Kiirunavaara and Luossavaara which are most rich in apatite, this fact being evident both macroscopically in the outcrops as well as in hand specimens, and generally also under the microscope. The most prominent dissimilarity is the predominance of the apatite over the ore minerals in the dikes, but this is of little consequence. More important is the occurrence of pneumatolytic minerals in considerable quantities in the dikes, even when not considering the apatite. The tourmaline is such a mineral, probably also the zircon, while the albite and the quartz do not necessarily require pneumatolytic processes for their development.

Among these minerals zircon and tourmaline are about as common in the ore bodies as in the dikes. In the former, feldspar and primary quartz are up to now not found at all. Augite, on the other hand, is not found in the latter, and the hornblende is rare. Flow-structures are seen as well in the ore bodies as in the dikes.

We find accordingly that the dissimilarities are on the whole very unimportant in comparison to the great resemblances existing between these different forms of concentration of apatite and iron ore, the dikes and the great ore bodies. These phenomena must therefore surely have almost the same origin, a fact that adds considerably to the interest of the studies of the former.

Origin of the apatite dikes.

It has been stated above that these dikes in their mineralogical composition show features indicating that their origin has been associated with pneumatolytic processes; especially into the dike-forming minerals there enter boron (tourmaline) and fluorine (apatite, tourmaline). But pneumatolytic minerals may crystallize from igneous or from aqueo-igneous solutions, or be deposited in solid rocks or open fissures as products of sublimation. As far as is known, the tourmaline does not seem to be formed in the last-mentioned manner, i. e. as hematite crystallizes in the crevices of a lava. When it, as in this case, evidently is a primary constituent of the rock mass containing it (that is, of the apatite dike), only the first two possibilities remain, between which naturally no distinct limit can be drawn.

The mineralogical composition of the dike mass as well as the structure, especially the flow-structure and the granophyric intergrowths, prove that it is not deposited from normal aqueous solutions.

The flow-structures show the dike mass to have been a viscous fluid before its crystallization, and the relation between the mineral constituents, that have checked each other's development or have crystallized in more or less regular intergrowths, indicates that the crystallization has been almost contemporaneous throughout the whole mass. As has already been stated by the writer in his preliminary report [14], especially the more regular intergrowths must be regarded as signs of crystallization under magmatic conditions.

In the report just mentioned, the dikes were characterized as *magmatic bodies, at the development of which pneumatolytic processes have played an important part.*

Many writers, and almost especially such as have given their attention to the origin of ore deposits, have made a considerable distinction between the magmatic and the pneumatolytic mode of origin. However, these two do not exclude one another, while the sharp distinction between them only serves to effect confusion, as it leaves no room for the numerous kinds of ores and rocks combining the characters of the two types and having generally crystallized from aqueo-igneous solutions. In his description of the syenitic and nepheline-syenitic pegmatite dikes of southern Norway [4], BRÖGGER has pointed out that the magmatic conditions have been predominating during the first stage of crystallization, while later on reactions of gaseous compounds mutually and with the already crystallized minerals have taken place to a rather large extent. GRUBENMANN has more recently [17] given an account of the characters of the pegmatites, based upon the considerable progresses of the physico-chemical petrography since the publishing of BRÖGGER'S monograph; he emphasizes that now the magmatic characters are predominant (eutectic structure) and now the pneumatolytic ones (»Schalenbau»).

According to the view of the writer, our apatite dikes are genetically similar to pegmatites at least with regard to the physico-chemical conditions of their crystallization. The flow-structure, the fine grain and the compactness of the dike mass indicate that the conditions in question have been chiefly magmatic. Whether one ought to call the origin of such a mass igneous or aqueo-igneous is really a matter of taste, as there surely must exist a transition between these two notions and the apatite dikes perhaps just represent this stage. The writer, at any rate, considers the term given in his preliminary report to be appropriate.

The dike minerals occurring in the wall rock close to the contact may on the contrary have originated through the reactions between gaseous compounds and the porphyry (compare the occurrence of tin ore in greisen.)

The relation between the dikes and the quartz-porphyry will be treated further on in connection with the mode of origin of the iron ores of the region.

Magnetite dikes.

Though these dikes are mineralogically rather similar to some of the above described ones whose chief constituent is the apatite, they differ so much from them in their geological mode of occurence etc., that it is necessary to treat them separately.

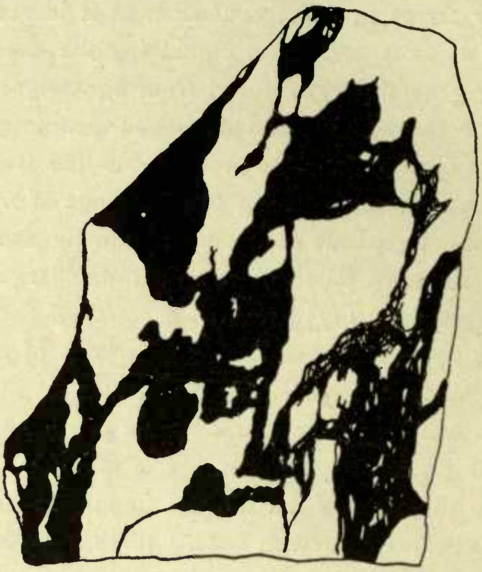

Fig. 51. Schlieren of magnetite in quartz-porphyry, east of Direktören, Kiirunavaara. 2/3 of nat. size. Black = magnetite; white = porphyry.

Distribution and mode of occurence. Macroscopic characters.

Dikes of this type occur almost exclusively on Kiirunavaara, in a zone parallel to the ore and at the utmost some hundred meters, in the most northerly parts of the mountain only some twenty or thirty meters from it. They are very small, only exceptionally reaching a width of some dm, and the length is often so inconsiderable that they have the shape of much elongated lenses. Their outlines are not at all similar to those of the apatite dikes; the dikes are winding and vary suddenly in width, they are often like schlieren. Transitions occur from sharply defined dikes to irregular streaks of magnetite in the rock groundmass. The phenocrysts of the porphyry are sometimes embedded in the magnetite near the border of a dike; they may also at times occur all over the dike

mass with the same distribution as in the porphyry. The last mentioned mode of occurrence has, however, been observed only in a single rather wide dike to the north of Vaktmästaren, near the hanging wall contact of the ore body. Especially the rather thin dikes are often branching and anastomosing, forming a real »stockwork» in the porphyry, as seen in fig. 51. The larger ones stand almost vertically, as is generally also the case with such systems of smaller veins.

The dikes consist almost entirely of magnetite, dense or finely crystalline, generally pitch black or bluish and resembling the ores of Kiirunavaara and Luossavaara. The colour is sometimes almost gray, caused by a considerable quantity of apatite mixed up with the magnetite, in other cases small plates of biotite or grains of pyrite are seen. The occurrence of feldspar phenocrysts is already mentioned. The phenocrysts of the above mentioned feldspar-bearing dike are much smaller than those of the surrounding porphyry.

Microscopic characters.

A slide from the middle of a large dike shows a finely crystalline magnetite mass with spots of biotite, generally fresh and strongly pleochroic, $\mathfrak{c} = \mathfrak{b}$ — dark brownish green; $\mathfrak{a}$ — colourless, the extinction is quite parallel. The magnetite is idiomorphic towards the biotite. There also occur small grains appearing to be altered titanite.

The ore with feldspar phenocrysts from the contact of a dike with the porphyry shows the following. The microperthite phenocrysts and patches of groundmass are embedded in a magnetite mass of the kind just described. Biotite is present in abundance together with quartz in rounded grains, this mixture partly replaces the groundmass and sometimes eats its way into the phenocrysts.

The above mentioned dike containing feldspar phenocrysts distributed throughout the whole mass is not very well known with regard to its shape and extension. It is very rich in apatite. A slide shows that the relations between the magnetite-apatite mass and the enclosed phenocrysts and fragments of groundmass are analogous to the case just described, and the replacing of the latter by quartz and biotite is very obvious. It is worth mentioning, that crystals of magnetite and of apatite are here and there enclosed in the phenocrysts. In the dike mass the magnetite occurs in crystalline lumps reaching some tenths of a millimeter in diameter, the apatite in elongated grains of about the same size.

Comparison to the Luossavaara dikes. Origin of the magnetite dikes.

The magnetite dikes of the quartz-porphyry are accordingly very similar to those occurring in the syenitic rocks of Luossavaara. The diffe-

rence is chiefly that titanite and hornblende, which are very common in the latter, are almost missing in the former, while their magnetite is more finely crystalline that of the Luossavaara dikes. Among the likenesses ought to be observed the occurrence of quartz and biotite in a similar way in both places, and the close connection with the wall rock, the dikes having sometimes almost the character of schlieren.

The relations to the wall rocks as well as the mineralogical composition show the dikes to be of igneous or aqueo-igneous origin. They can scarcely have originated through deposition from aqueons solutions, as they lack the minerals characteristic of such veins with the exception of the nearly everywhere present quartz; on the other hand it is remarkable that they contain no tourmaline. No structural features occur, which might give information of the physical conditions during the crystallization of the dike mass. The association of quartz with magnetite, appearing especially in the dikes of the quartz-free rocks of Luossavaara, seems, however, to denote that the dike masses are deposited from aqueo-igneous solutions. The replacing of the wall rock by quartz and biotite is probably a pneumatolytic phenomenon. The close relations existing between the dikes and their wall rocks prove, that the material of the former must originate from the porphyry magma; the discussion of the process of differentiation must, however, be deferred to a following chapter..

Ore bodies related to the dikes.

In an area on the slope of Kiirunavaara, 320 to 500 meters east of the ore boundary at Direktören, there occur in the quartz-porphyry peculiar concentrations of magnetite, which no doubt are of an origin similar to that of the dikes.

Most ore bodies are lenticular with a length of only some few meters. Their outlines are now sharply defined, though sinuous, now somewhat diffuse. The lenses very often, especially at the ends, change into systems of ore dikes; on account of this they cannot be enclosed fragments of the kind described further on (p. 154). These dikes are now straight, now winding. There also occur schlieren and patches of ore and sometimes an intimate mixture of magnetite and porphyry material.

Fragments of porphyry are often in great quantity enclosed in the ore lenses, which therefore may be considered as an ore breccia with short

and wide dikes. The fragments always belong to the quartz-porphyry and are generally quite similar to the phase surrounding all these concentrations. They are generally rounded, but sometimes angular.

Within the rather large lenses the ore is dense and bluish black, with patches of apatite, it is consequently similar to the main ore of Kiirunavaara. In other cases much apatite is present, being rather finely distributed and giving the ore a grayish colour.

There is often seen a distinct schlieric alternation of bands of different composition. Also quartz is sometimes present in drusy masses. In this matrix of ore rich in apatite there generally lie great quantities of ore fragments, seldom more than one or a few cm in length, often rounded, but sometimes rather angular. Some of them consist of pure magnetite, others of almost only apatite, and between these extremes all transition forms are to be found; some fragments consist of rudely »stratified» ore.

The porphyry surrounding these ore concentrations is the usual reddish quartz-porphyry, it is now and then somewhat heterogeneous and schlieric close to them. It contains some diffuse ore fragments.

The microscopic examination shows that the ore mass sometimes is a mixture of apatite and magnetite with a suggestion of trachytoidal structure and resembling the ore of Kiirunavaara-Luossavaara. The gray matrix, however, is in most cases a quartz-porphyry, exceedingly rich in crystal aggregates of magnetite and in apatite prisms. There are also present rather much biotite and calcite, some orthite and new-formed quartz. The ore pieces are not sharply defined.

The nature and origin of these ore concentrations is difficult to determine. They are evidently no friction breccias, neither concentrations of inclusions of ore in the porphyry. Their shape does not resemble that of younger dikes and veins.

They must therefore have been segregated from the porphyry during the solidifying of the latter. The differentiation in ore on one hand and in porphyry on the other hand is partly incomplete. These phenomena are very similar to the magnetite-apatite schlieren and dikes of Painirova (see p. 270).

In maps showing the distribution of the ore bodies on Kiirunavaara and immediately north of this mountain there are seen, beside the main mass, some ores parallel to it, lying north-east of it and very probably surrounded by quartz-porphyry on both sides. The shape and extension

of these ore bodies has been examined partly by magnetometric measurements, partly by diamond drilling. It appears to the writer to be very probable, that these ore bodies are quite similar to the above mentioned ore segregations and to the dikes. The »Konsul ore», southeast of Jägmästaren, whose largest ore body is about 350 meters in length, has been examined by means of magnetometric measurements and by excavations, which have now collapsed. It is possible, that this ore body and the little known ones forming its continuation to the south, originally have been connected with the main ore and have been brought into their present place through a fault striking west-east.

Mineral veins.

Beside the apatite and the magnetite dikes just described, there occur in the quartz-porphyry rather numerous but always very small veins of a different composition and probably also of an origin different from that of these dikes.

Veins of white quartz are present here and there within nearly the whole of the quartz-porphyry area and are much more common than within the syenitic rocks, where they are only seldom seen; as a rule they reach a width of only about 1 dm and are often somewhat drusy. In some cases they contain bunches of black tourmaline, as for instance between Kiirunavaara and Luossajärvi and on Luossavaara within the agglomeratic zone. Crystal plates of hematite are often seen.

In the quarry at south-eastern Kiruna there occur numerous veins of a somewhat varying composition. The largest reach a width of several dm, others are discovered only by the aid of the microscope. The chief vein-forming mineral is white quartz, often associated with coarsely crystalline yellow siderite, or perhaps ankerite, in considerable quantities, now forming the borders of the vein, now more irregularly alternating with the quartz. The siderite alters to brown hematite. Pyrite is often seen in the quartz or in the surrounding porphyry, occurring in pentagondodekaedrons with a diameter of up to 5 mm, and in hexaedrons reaching a size of several cm. Grains of chalcopyrite are also present. Crystal plates of hematite are seen here and there, and very small patches of red feldspar also occur in the quartz. Lastly there is often seen a mineral occurring in irregularly columnar individuals reaching a length of up to 5 cm, its hardness is about 5,5, the colour of a freshly broken surface is pitch

black, the streak is greenish gray. It shows a well developed cleavage system. These characters seem to indicate orthite, and a comparison to the plentiful supply of this mineral from Swedish pegmatite dikes, possessed by the Geological Institution of the University of Upsala, also showed the correctness of this supposition. In thin sections the orthite in ordinary light shows the pleochroism in gold green and reddish colours characteristic of the small grains of the same mineral distributed in the porphyries, in the apatite dikes etc.

All the vein-forming minerals also occur as small patches in the porphyry.

Other veins in the same place are never more than one or a few cm wide and are very intimately connected with their wall rock. They consist chiefly of magnetite and quartz, the former generally being predominant, in a finely crystalline mixture. Sometimes there also occur pyrite crystals. White calcite and purple fluorite occur locally.

The veins are on both sides surrounded by a red zone in the otherwise dark brownish gray porphyry.

A slide shows that this colour chiefly depends on the occurrence of red pigment in the groundmass. The rock is somewhat altered; beside muscovite rather much calcite has also been formed. Small lenses and short stringers running parallel to the large vein consist of quartz, clear polysynthetically twinned albite feldspar and calcite. The vein is chiefly made up of quartz and magnetite in about the same proportions. The former occurs in isometric grains generally reaching a diameter of $0{,}1$ mm, but larger in spots. The magnetite partly forms a dust-like impregnation in the quartz mass in wavy streaks giving the impression of a flow-structure, and is partly concentrated in rather large crystal lumps reaching a diameter of up to 1 mm. Calcite is present here and there, albite is sometimes abundant. There also occur some tourmaline crystals, $0{,}3$ mm in length and embedded in quartz. The pleochroism is: $O =$ bluish green $E =$ pinkish, absorption $O > E$.

A few hundred meters north of the quarry there occur some veins consisting chiefly of white calcite, some quartz and siderite; bluish magnetite is present partly as rounded grains in the calcite, partly as thin lamellæ in the same, often with a surface of a square cm but only a few tenths of a millimeter thick. Siderite occurs here and there, pyrite and chalcopyrite are present both in the vein and in the wall rock. There are also seen a few small columns of orthite and some tourmaline needles.

In the agglomeratic zone of Luossavaara there occurs a vein with a length of about 2,5 meters and a width of about 0,3 meters, consisting of quartz, black crystalline magnetite and some pyrite. Drusy cavities occur. Under the microscope there also appear small quantities of calcite, some biotite plates and grains of rutile.

All these veins are, according to the view of the writer, results of the last stages of the volcanic activity of the quartz-porphyry magma, they are deposited from aqueo-igneous or aqueous solutions and contain some relatively rare elements, as boron (tourmaline) and cer (orthite), but consist chiefly of common vein minerals: quartz, calcite, siderite. The occurrence of magnetite, tourmaline and orthite seems to indicate that normal aqueous conditions have not been predominating.

Inclusions of ore fragments.

Outside the agglomeratic zones there occur isolated fragments of syenite-porphyries here and there in the quartz-porphyry, but not in the most southerly or easterly parts of it. But commoner than these are the inclusions of magnetic iron ore known already from LUNDBOHM's works in the nineties and always noticed by geologists. We find for instance, that in the great discussion of the genesis of the iron ores, at Stockholm, 1906 [76] they were held forth as reasons against the view that the ore bodies of Kiirunavaara and Luossavaara should be younger than their hanging wall, i. e. the quartz-porphyry.

The distribution of these inslusions as far as the writer has been able to establish, is seen on the sketch map, fig. 52. It appears from it that they occur within a rather regular area, not adjacent to the ore of Kiirunavaara, but on the contrary in the immediate neighbourbood of that of Luossavaara, and not at all in the most southern, northern and eastern parts of the quartz-porphyry mass. They seem to be most numerous around the south end of lake Luossajärvi and on Luossavaara near the ore. On the summit of this mountain within an area of about 0,12 square meter the writer has counted 14 fragments having a size of 2 to 7,5 cm, and besides several smaller pieces.

The size is very varying, many fragments reach but a few mm in diameter, while some (on Luossavaara) reach a length of 30 to 40 cm. Some of them are rounded or have sinuous outlines, others are sharply

angular. The border towards the rock is macroscopically often well defined. Cracks filled with porphyry-groundmass are sometimes observed.

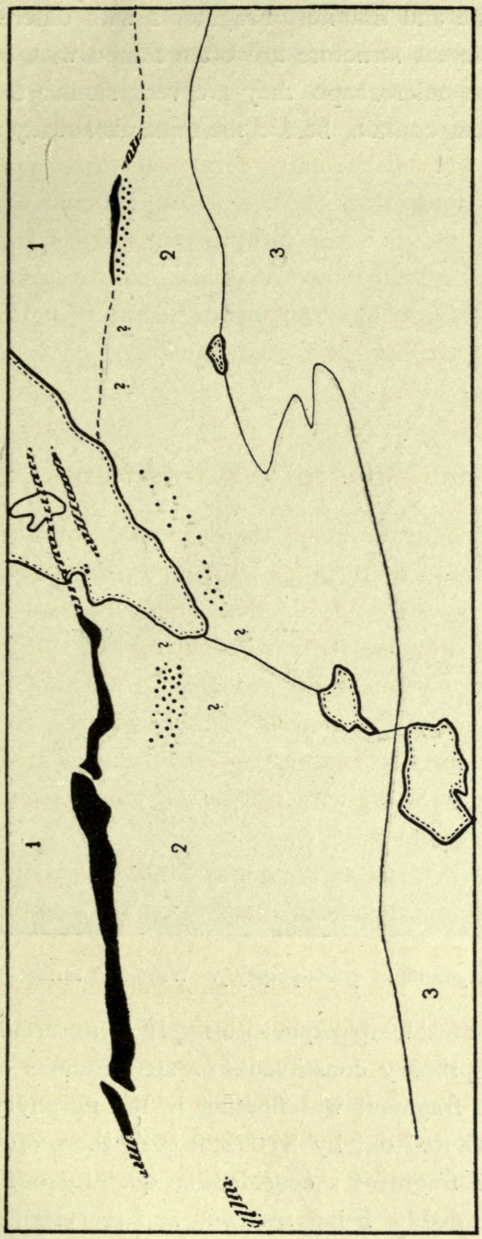

Fig. 52. Map showing distribution of ore inclusions in the quartz-porphyry. Scale 1: 50000. Areas, where inclusions are observed, are dotted, the dotting gives an approximate figure for the relative abundance of the inclusions. (1 syenite rocks, 2 quartz-porphyry, 3 Hauki complex.)

In their composition and structure the fragments are quite similar to some varieties of the ores of Kiirunavaara and Luossavaara. They are finely crystalline or dense and consist of magnetite and apatite in varying

proportions, now equally distributed, now concentrated, in streaks adn patches; pyrite is often observed. STUTZER [62, p. 567] has also in a fragment observed calcite and titanite. Fragments with different quantities of apatite and with different structure are often mixed with one another.

Even under the microscope they are very similar to the ore of the great bodies but often contain, beside the minerals already mentioned, biotite and quartz in considerable quantities. It is uncertain whether these minerals occur as primary constituents or are products of contact metamorphism when the fragment was floating in the porphyry magma.

Fig. 53. Ore fragments in quartz-porphyry. Weathered surface. Nat. size.

As has been pointed out by STUTZER [62], there often occurs in the porphyry close to a fragment a considerable quantity of magnetite in idiomorphic crystals, probably being resorbed and recrystallized parts of the fragment.

The fragments probably originate from a larger ore mass which in composition and structure must be similar to the ores of Kiirunavaara and

Luossavaara. It is quite impossible that these numerous fragments should be as many concentrations of the magnetite and apatite content of the quartz-porphyry; even when leaving other features out of question, we see that their very shape is irreconcilable to such a supposition. On the other hand they can of course not be *proved* to originate from the ore zone of the two mountains just mentioned, even if this seems to be rather probable. Their distribution is simply explained by the hypothesis that the quartz-porphyry at the eruption has broken through an ore mass somewhere in the neighbourhood of south Luossajärvi, and the part containing fragments of it had then during the outflow of the porphyry extended and assumed its present shape; the explanation will be analogous under the supposition that the quartz-porphyry should have flowed out from a long fissure.

It is possible that the break between the ore of Kiirunavaara and that of Luossavaara has come into existence in this manner.

Dikes of quartz-porphyry and of diabase.

Quartz-porphyry.

Distribution and mode of occurrence. Macroscopic characters.

Such dikes occur only on Kiirunavaara, where the syenitic rocks are cut by one having a length of 2400 meters and by some shorter ones, some of which appear to be younger than the ore body.

The great dike is found furthest north about 600 meters west of Grufingeniören, where the following profile has been registered, beginning from the east:

1. Medium-grained syenite.
2. Quartz-porphyry (5 meters wide).
3. Medium-grained syenite ($2{,}_7$ meters wide).
4. Quartz-porphyry ($13{,}_5$ meters wide).
   Covered.

The visible contacts run almost north and south, but the area exposed has a length of only some ten meters. The next exposure is found 200 meters south of the other one, the dike outcrops there for a length of about 200 meters. The profile is as follows, beginning from the east:

1. Syenite.
2. Quartz-porphyry (18 meters wide).
3. Syenite (2 » »).
4. Quartz-porphyry (1 » »).
5. Covered (9 » »).
6. Quartz-porphyry (2 » »).

The rock is then covered, with numerous morainic boulders of syenite.

The contacts have the same direction as in the precedent exposure. There are accordingly two parallel dikes of quartz-porphyry present in both of them, in the latter exposure with a width of respectively 18 meters and probably at least 12 meters, separated by a band of syenite, only a few meters wide. Numerous apophyses with a width of only about 1 cm penetrate the wall rock.

The morainic covering is further south unbroken, as has already been mentioned in the description of the syenitic rocks, and at a rather great distance from the ore there are only two outcrops of any kind of rock. The most easterly one of the two, which is located at the bottom of a temporary lakelet, about 340 meters west of the summit of Kapten, consists fortunately enough not only of syenite-porphyry but also of quartz-porphyry, the latter having a width of 7 meters and occupying the western part of the outcrop; the contact has almost a north-southerly direction.

The most southerly exposure is found about 50 meters west of the summit of Jägmästaren. Near a small prospecting excavation, which has collapsed, there lie almost exclusively fragments of quartz-porphyry, showing all transition forms from the relatively coarse rock of the middle of a dike to a porphyritic phase with dense groundmass, in actual contact with syenite-porphyry that contains hornblende nodules. An occurrence of quartz-porphyry must evidently be present here.

It is of course very doubtful whether the two more southerly exposures are connected with one another and with the two more northerly ones. The direction of the double dike forming the two latter will, if it is extended on the map, go right across the summit of Landshöfdingen, the four exposures are accordingly not lying in a straight line with one another. There is, however, no reason why the dike should be quite straight, and it is possible that the somewhat steeper slope of the mountain at the more northerly exposures also may have something to do with the matter. The foot wall on Landshöfdingen and Professorn is so well exposed that it is no difficulty to ascertain that no such dikes occur there. It is also possible that the dike may have been displaced by a fault between Jägmästaren and Professorn.

The dike seems to stand almost vertically, at least in the exposure west of Geologen.

The rock differs widely from the already described quartz-porphyry. It is porphyritic with numerous red feldspar phenocrysts generally reaching a length of 1 or a few mm, sometimes even as much as 1 cm; there also

occur quartz phenocrysts in about the same quantity. The groundmass is red or reddish gray, it is rather coarse in the middle of the dike, but grows quite dense and often dark gray near the contact. The apophyses are generally porphyritic with dense groundmass, but they are sometimes more coarse-grained with granitoid structure. Coarser streaks of this kind occur now and then in the contact phase of the main dike.

West of Geologen there occurs a much smaller dike running parallel to the larger one about 40 meters east of it, it cuts fine-grained syenite. It is at least 10 meters in length and has a width of about $0{,}5$ meter. The rock is porphyritic, with small phenocrysts of feldspar and quartz in a dense, reddish gray groundmass.

Within the ore of Jägmästaren, near the northern end of this summit, there has been observed a small exposure of a porphyritic rock of a reddish gray colour, evidently belonging to this group; the contacts with the ore are not exposed. Besides there occurs a band, only a few dm wide, of a similar, but highly weathered rock.

In the ore of the same summit but very near the hanging wall, there has been found a red highly weathered rock, which doubtless also belongs to this group.

These quartz-porphyry rocks are accordingly even younger than the ore, but their relations to the quartz-porphyry forming its hanging wall are unknown, on account of the thick moraine covering the southernmost parts of Kiirunavaara.

Microscopic characters.

The *mineral constituents* are quartz and feldspar, magnetite in small quantities, isolated crystals of zircon, irregular individuals of titanite, biotite and hornblende, some muscovite and sometimes also calcite (allotriomorphic). The feldspar, the phenocrysts as well as the grains in the groundmass, is chiefly microperthite, very similar to that of the syenite, but more rich in potash-feldspar. The plagioclase component is albite, often very finely twinned, sometimes cross-twinned (albite and pericline laws), now and then showing no striation even when subject to a 450-fold magnifying power. The stripes of potash-feldspar often show the kind of cross-twinning characteristic of the microcline, their refraction and birefringence are much lower than those of the albite. Mannebach twins occur even in this microperthite. In the dike cutting the ore of Jägmästaren, free microcline and albite are seen in the groundmass, but the phenocrysts are microperthite.

The biotite is olive brown and strongly pleochroic. The hornblende resembles that of the syenite and occurs, as well as the biotite, only in a slide from the contact of the main dike with the medium-grained syenite, and even there only sparingly.

Titanite has been found in a few places, for instance in the groundmass of the smaller dike west of Geologen, where it occurs in an individual with a suggestion of idiomorphism.

The structure. One slide from the middle of the main dike shows phenocrysts of feldspar and quartz in an aplitic groundmass of the same minerals. The feldspar phenocrysts are often composed of several microperthite individuals and reach a length of up to some mm, those of quartz have the usual habit of bipyramides and are occasionally somewhat corroded. The quartzes of the groundmass are now and then idiomorphic and differ from the phenocrysts nearly only by their smaller size (0,2 to 0,4 mm). They lie in a feldspar mass with granitoid structure, whose individuals reach somewhat larger dimensions than those of the quartz. Granophyric intergrowth of feldspar and quartz has been observed only locally and in a very small quantity.

This aplitic structure is probably less widely distributed than a distinctly granophyric one. In this type there occur phenocrysts of quartz similar to those of the precedent one, and also phenocrysts of feldspar in broadly rectangular sections, in a groundmass of the same minerals altogether in a very beautiful granophyric intergrowth, similar to the common type of the graphic granites, and not the rather uncomplicated structure already known from the quartz-bearing phases of our syenite and from the coarse phase (type 3) of the hanging wall quartz-porphyry. The feldspar phenocrysts are surrounded by a granophyric zone of quite the same shape as themselves, the feldspar of which extinguishes at the same time as the phenocrysts. Also the quartz generally belongs to one individual. In some sections of such micropegmatite individuals, there occurs in the centre a rectangular area with a very fine intergrowth, this is surrounded by a coarser frame. The quartz particles are generally angular, sometimes triangular, occasionally hook-like as is often the case in graphic granites. The quartz phenocrysts are also often surrounded by a granophyric zone. A feldspar is sometimes intergrown with several different quartz individuals, the contrary being more seldom the case. The microperthitic stripes in the feldspar continue independent of the quartz.

A slide from the contact with the syenite shows the following. Quartz phenocrysts are rather numerous, in their habit they resemble the already described ones and are now idiomorphic, now rounded and corroded, having a size of 0,3 to 1 mm. The feldspar phenocrysts are more numerous and larger, they show rectangular sections or are composed of several individuals; they occur sometimes in aggregates with quartz phenocrysts. The groundmass consists of quartz and feldspar in the usual proportions, the individuals seldom reaching a diameter of 0,1 mm; the structure is granophyric but very little complicated, somewhat similar to the above mentioned structures of some phases of the syenite. Quite close to the contact, in a zone about 0.6 mm wide, with microgranitic structure, the individuals reach a diameter of one or a few hundredths of a millimeter. The contact is very sharply defined; some feldspars are detached from the syenite, immediately around them and along the contact the granophyre contains a great quantity of magnetite in small crystals, sometimes clustering together in long lumps. The syenite shows no contact phenomena.

An apophysis, 1,7 cm wide, contains feldspar and quartz phenocrysts as the precedent slide, the groundmass is altogether similar to the immediate contact zone of the latter and is rich in magnetite, which mineral seems to make up nearly 20 per cent of the volume of the groundmass. It has also been found enclosed in the most peripheric parts of a quartz phenocrysts. —

The smaller dike west of Geologen is similar to the last described slides

with very fine-grained, micrograniitic groundmass, only near the contact containing any considerable quantity of magnetite. Among the phenocrysts, there are some composed of quartz and feldspar with no granophyric intergrowth, and one characterized just by such a structure. It is probably a quite mechanically formed agglomerate of some feldspar phenocrysts with uncommonly broad, granophyric rims, which are sharply defined towards the microgranitic groundmass.

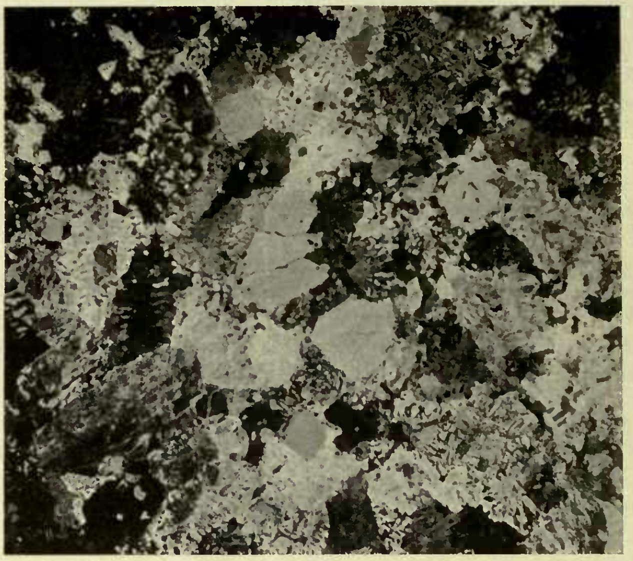

Fig. 54. Quartz-porphyry from the middle of the main dike, west of Geologen, Kiirunavaara. Nic. +. Magn. 14 times.

Micropegmatite phenocrysts are known from several porphyritic rocks rich in quartz (see ROSENBUSCH II p. 509) and from pegmatites. Their origin seems to have depended on the fact that the average composition of the magma has been very similar to that of the eutectic mixture of quartz and the kind of feldspar in question.

The largest dike cutting the ore of Jägmästaren contains few phenocrysts of feldspar and quartz of the usual type, the groundmass is microgranitic and relatively coarse, the individuals reaching a size of about 0,1 mm.

Chemical characters.

It appears from the description of the granophyres given above, that their feldspar is very similar to that of the syenitic rocks and the quartz-porphyry in being a microperthite, composed of albite and potash-feldspar, and also with regard to its twinning laws. But a comparison to the analyzed rocks of preceding groups shows that the granophyres probably contain almost as much of the orthoclase molecule as of albite. The SiO_2 percentage has in one case been determined by the writer to 76,02.

Diabase.

Diabase has been found only in a diamond drill hole (»Mormässa») south of Jägmästaren. The entire hole, which reaches a depth of 103 meters, runs through such a rock, a medium-grained diabase rich in dark minerals. The hole has probably met a considerable dike mass.

The main constituents are plagioclase, augite and magnetite. The plagioclase is broadly lamellated and limpid, only seldom somewhat altered. The refraction is always considerably higher than that of the Canada balsam, the symmetric extinction angle exceeds 25°. These characters make it almost certain that this feldspar is labradorite, though probably a little basic form. The augite is similar to that of the syenitic rocks. It is partly uralitized, the amphibole is further on often altered to chlorite. Biotite occurs in irregular plates, containing three systems of rutile needles intersecting one another at an angle of 60°. Besides there are scattered brilliant crystals of pyrite and some grains of epidote.

The structure is ophitic. The plagioclase forms rectangular sections reaching a length of about 1 mm, between them the scarcely less big individuals of augite and lumps of magnetite are squeezed in.

It is impossible to get further knowledge of the relation of the diabase to the other rocks of the region.

The Rektor and Nokutusvaara ores, and accompanying rocks.

Introductory remarks.

This group comprehends the uppermost (easternmost) parts of the quartz-porphyry and the rocks next in age to it, further some occurrences of magnetite ore and of hematite. The rocks treated here are thus: Quartz-porphyry, porphyry of the Rektor type (with quartz phenocrysts, probably a tuff), dense quartzites (and, very subordinate, sericite schists), syenite-porphyry and quartz-porphyry of the Nokutus type. With the exception of only the first-mentioned one, all these rocks are referred to the Hauki complex. The Rektor type occurs only in the part of the complex described here, while the quartzites, together with sericite schists, have a great extension (see the map). Even of the syenite-porphyries of the Hauki complex only a very little fraction is treated here. The Hauki complex has been studied by LUNDBOHM, and recently by ZENZÉN, who gives a more complete account of it. The reason for the present writer's studying and describing part of them is their being of interest for the understanding of the mode of eruption of the quartz-porphyry, further the occurence within them of several ore deposits. These deposits are partly magnetites, partly hematites. The magnetites, which are rich in apatite, occur at the upper contact of the quartz-porphyry (Luossavaara), or as schlieren in a syenite-porphyry (northern part of the Nokutusvaara ore field), the relations of this porphyry to the other rocks of the region are unknown, but it is probably older than the Hauki complex. The mode of occurence of some Nokutusvaara ore bodies is not known.

The hematites occur within the dense quartzites, as shown on the map. Very often an ore zone forms the bottom of this rock. This lowest level only is described by the present writer, except in the Nokutusvaara ore field, where all ore exposures have been studied by him.

Exposures.

The southernmost exposure studied by the writer is located in north-eastern Kiruna, where a narrow hematite band separates the quartz-porphyry from the syenite-porphyry of the Hauki complex. Between Kiruna and Luossavaara there are some exposures of about the same kind. On the slope of the mountain, some prospecting work has been made on the magnetite ore (Rektor ore) occurring there, and there are isolated outcrops and prospecting excavations to about 400 meters south of Nokutusjärvi. In the »Nokutusvaara ore field», from the northern shore of Nokutusjärv and up the eastern side of Hopukka, there are only a few natural outcrops, the ores being, however, in many places exposed by diggings.

On account of the peculiar characters of some rocks and ores, each exposure or group of exposures will be treated separately in the following, in the same way as the syenite-porphyries of Hopukka were treated.

Description of the exposures, petrographic characters of the rocks and ores.

Kiruna.

Within the municipality, about 480 meters right south of the southern end of lake Matojärvi, there is an exposure showing the contact between the quartz-porphyry and hematite ore, further east follow syenite-porphyry (belonging to the Hauki complex), and dense quartzite. The exposure consists of some natural outcrops; besides, there was in the summer of 1909 a trench for the installation of waterpipes, running at right angles to the direction of strike.

The quartz-porphyry is here of an intensely red colour with small feldspar phenocrysts. It contains irregular grains of chalkosite, and the jointing planes have a malachite coating. Bunches of tourmaline are also seen. Near the hematite ore the rock is interwoven with small irregular quartz stringers. The microscopic examination shows the badly idiomorphic feldspar phenocrysts to be microperthite. The potash feldspar, which often constitutes the periphery, is of a deep red colour, due to red pig-

ment. The quartz occurring in peculiar branching patches, the groundmass is probably recrystallized. Small areas of a beautiful sphærulitic structure are occasionally seen.

East of the quartz-porphyry there is a band of apatite, scarcely more than 1 meter wide. The mass is very finely crystalline and shows a beautiful alternation of pinkish and dark gray bands. This banding seems to be a fluidal one. A slide of the pinkish phase shows the following. The apatite occurs in slender prisms of varying sizes, generally only one or a few tenths of a millimeter in length, often beautifully trachytoidally arranged. Quartz occurs in isometric individuals, poikilitically larded with apatite crystals. There also occur hematite, zircon and some muscovite. The gray bands are similar to the pink ones, being, however, more rich in hematite, which occurs as jagged ribs reaching a length of some tenths of a millimeter.

The hematite zone, which is a few meters wide, is situated east of the apatite. The ore consists chiefly of rounded or somewhat angular, sometimes, however, sinuous fragments embedded in a matrix to a great extent made up of crystalline hematite. The fragments as a rule reach only one or a few cm in diameter, they consist of lean ore, sometimes of quartz containing only small quantities of ore minerals, and are dense or very finely crystalline and of a bluish or black, sometimes gray, colour. The streak is most often red, indicating hematite, but magnetite is always present, sometimes even predominant. Besides there occur plates or angular lumps of scaly sericite. No regular bedding appears.

Under the microscope the matrix is seen to consist chiefly of quartz and hematite. The quartz occurs in now rounded or elongated, now angular, sometimes pseudo-bipyramidal grains reaching a diameter of 0,2 to 0,5 mm and also in smaller, always rounded individuals. The hematite occurs in crystals with a diameter of 0,1 to 0,6 mm, they show acicular or isometric sections and are presumably tabular. Rather small individuals form a fine impregnation in the quartz mass. Small plates of muscovite are seen here and there.

The fragments (pebbles) consist of a finegrained quartz mass, generally very rich in iron ore minerals. These are now very finely distributed and now occur in small aggregates reaching a diameter of 0,05 to 0,10 mm; their distribution is often irregular, almost schlieric. The grain and structure does not make it possible to distinguish quantitatively between hematite and magnetite crystal forms, and therefore it cannot be settled how much of the former mineral may be of a martitic nature. In one fragment there are seen numerous, about 0,1 mm long, narrow and straight areas of quartz (generally several grains) in a more fine-grained groundmass rich in ore minerals. In ordinary light the phenomenon is rather similar to some phases of magnetite-syenite-porphyry. As ZENZÉN in the conglomerate with hematite pebbles of the Hauki complex has

found pebbles consisting of quartz and hematite, the former evidently having replaced the feldspar of a porphyritic rock, it is rather natural to attribute the case in question to the same origin. Small grains of baryte are sometimes seen. The mineral is known by its refraction, which is somewhat higher than that of the apatite, its birefringence, which scarcely seems to be more than $0{,}012$, and the cleavage. It is colourless.

In one of the sericite masses there is seen a small individual of tourmaline with the pleochroism O = brownish green, E = pinkish; absorption O > E.

The outlines between the matrix and the fragments are under the microscope not always easy to distinguish.

Claim of Hildarius.

North of this exposure there is none of this level until in the *claim of Hildarius*, about 480 meters north of the northern end of Matojärvi. There is a prospecting trench at almost right angles to the direction of strike, it shows, beginning from the west:

1. Quartz-porphyry with feldspar phenocrysts in a pinkish groundmass, richly impregnated with crystalline hematite; besides there are seen small veins of finely crystalline apatite or of quartz with crystal plates of hematite (9 meters).

2. Finely crystalline apatite with sinuous, narrow stripes of hematite ($3{,}5$ meters).

3. Hematite ore, furthest west containing some rounded quartz lumps. The bedding is marked by short streaks of richer, scaly ore and of gray quartz, it strikes in an almost north-southerly direction. A band of rock occurs in this ore bed, it is probably a few meters wide. The rock is a massive syenite-porphyry, fine-grained and of a red colour; it is very rich in crystalline hematite. (The entire width of the ore bed and this band is about $18{,}5$ meters.)

4. A white quartzite rock very rich in sericite, without visible stratification, at the contact with the ore intersected by some narrow and winding hematite veins. (Only a few meters are exposed.)

Under the microscope the quartz-porphyry (1) shows the following characters. The feldspar is albite, the size of the individuals varying from about $0{,}1$ mm, which is most common, to about 1 mm, the larger crystals occur in nodule-like aggregates. Quartz is present rather sparingly among the feldspars; there also occur some hematite, calcite, zircon and apatite. *This feldspar rock is to a great extent replaced by a mass of quartz* in irregular, often polygonal grains reaching a size of about $0{,}1$ mm. In this quartzmass there occur rather small fragments of the feldspar rock, sometimes nodule-like and containing iron ore (hematite or magnetite) squeezed in between the albite individuals, occa-

sionally also with concentrations of apatite. Single feldspars are in this manner embedded in quartz. The outlines of these inclusions are irregular and fringed, and »plugs» of quartz are seen in them.

The syenite-porphyry occurring within the ore bed is made up of feldspar, quartz, hematite and muscovite. The feldspar occurs in elongated individuals (broadly rectangular sections), generally about 0,5 mm in length. The abundance of small muscovite plates renders the discerning of the outlines between the different grains and of the optical proporties very difficult.. But a striped lamination may often, however, be seen without any great difficulty, and it is therefore probable that albite is present. The quartz occurs in small quantities, it forms allotriomorphic grains. The hematite constitutes 10 to 15 per cent of the rock volume, it occurs in jagged crystalline aggregates in or between the feldspars.

The quartzite rock is macroscopically very similar to one outcropping on the eastern shore of Matojärvi, quite close to the water. The latter is a fine-grained quartzite rich in sericite and contains groups of rather big quartz-grains, perhaps scattered phenocrysts. On a polished surface the rock is distinctly seen to be composed of various quartzitic fragments.

Claim of Sigfrid.

The next exposure is located about 140 meters further north in the *claim of Sigfrid*, where there has also been dug a prospecting trench at nearly right angles to the direction of strike. This trench has partly collapsed. At its western end there is seen quartz-porphyry, further east hematite ore resembling that of Hildarius. The quartz-porphyry is cut by a vein, some dm wide, consisting mainly of sericite. Under the microscope there are seen single albite phenocrysts, interwoven with fine strings of sericite; there also occur stripes of quartz in irregular fringed grains with a diameter of some tenths of a millimeter, together with limpid albite, sometimes cross-twinned. Single prisms of apatite and well idiomorphic zircon crystals also occur, and grains of magnetite and of ferruginous carbonate. This vein has mostly the appearance of being only a much altered part of the quartz-porphyry, the albite phenocrysts for instance are very similar to those occurring in the same.

Claim of Apollonia.

200 meters further northwards there are in the north-eastern corner of the *claim of Apollonia* a small prospecting pit, and excavations east and west of it. This profile shows more to the west a breccia (12 meters exposed), then magnetite ore very rich in apatite (about 20 meters) and at last a fine-grained, red feldspar rock.

The breccia consists of angular or sinuous, in a north-southerly direction elongated fragments of the common quartz-porphyry, embedded in a quantitatively subordinate, white or gray matrix. The size of the fragments varies from less than 1 cm up to 6 dm; their outlines are often diffuse. The matrix consists mainly of finely crystalline apatite with some magnetite. Pure apatite often occurs as a border along a side of a fragment or forms winding, fine veins. The magnetite is often concentrated in rounded or elongated lumps; it is partly quantitatively predominant and the matrix may then be called a magnetite ore, rich in apatite.

The rock of the fragments is even under the microscope rather similar to the common quartz-porphyry, but the groundmass is unusually coarsely microgranitic (the feldspars reaching a size of 0,1 mm), and the quartz content is very low. The groundmass is probably recrystallized. The rock is rich in muscovite and calcite, both evidently of secondary origin. The constituents of the matrix are, beside the chief minerals apatite and magnetite, the following: calcite, quartz, muscovite, albite and zircon. The apatite occurs in elongated grains, generally reaching a length of 0,2 to 0,6 mm, the magnetite in small idiomorphic crystals. The quartz forms mesostasis to the apatite and the magnetite, the calcite occurs in irregular grains. Of albite there occur a few, isometric grains, it is limpid and broadly lamellated. The muscovite and the zircon occur in the same manner as in the already (p. 139) described apatite dikes of the quartz-porphyry, to which this breccia evidently is similar in all principal respects.

The magnetite ore is dense or finely crystalline. It is very rich in apatite, which is now finely distributed, giving the ore a grayish colour, and now forms irregular lumps and lenses or bed-like bodies. These concentrations are finely crystalline and of a grayish white or pinkish colour.

The feldspar rock bordering the ore[1] on the east is massive, but contains irregular streaks and patches of hematite ore, generally with the longer axis parallel to the contact, and is in part altered to scaly muscovite.

The microscopic examination shows that the chief constituent, viz. the feldspar, appears in individuals reaching a size of 1 or a few mm. Most of them are, however, by strings of muscovite split into small pieces. Limpid, broadly lamellated albite occurs here and there, especially at the borders of the individuals. The rest of the feldspar is rich in red pigment, its refraction is considerably lower than that of the albite. It is therefore probably potash-feldspar. Between the large feldspars, aggregates of small albite grains are sometimes seen. Quartz occasionally forms mesostasis, hematite occurs sparingly, zircon and apatite are very rare.

The hematite zone is not exposed here, the ore visible in an excavation some 100 meters more eastwards belongs to a higher level.

[1] Neither of the contacts of the ore is distinctly exposed.

Claims of Rektorn and of Julia.

In *the claim of Rektorn* there are three small prospecting pits in the magnetite zone, but in all these there is seen nothing but ore. The two most southerly ones are situated about 200 meters north of the exposure in Apollonia, the third lies about 140 meters further to the north. Close by it there is a similar exposure in the *claim of Julia*. The width of the magnetite zone seems to amount here to at least about 30 meters. By magnetic measurements it has been stated that the magnetite ore exposed in these claims is connected with that of Apollonia.

The ore is very similar to that of Apollonia. It is magnetite, but often rich in finely distributed hematite (martite?); it is bright blue, very hard, and has an uneven fracture. The apatite, which is white or pinkish, is very finely distributed or concentrated in big lumps and nests or in bed-like bodies, causing the appearance of a rather irregular parallel-structure in the ore. Its quantity is always rather great, and in the most northerly exposure it even seems to surpass that of the magnetite. Occasionally it contains some carbonate.

A slide of an apatite concentration shows rather much albite feldspar, which is surely no foreign inclusion. It is partly altered to muscovite. Plates of this mineral are distributed all through the apatite mass. Zircon is present in rather great quantity, in thick prisms reaching a length of 0,2 to 0,3 mm, without terminal faces. The structure seems to be similar to that of the Kiirunavaara-Luossavaara ores. In one slide there is seen a beautiful trachytoidal flow-structure in the apatite mass.

The ore is cut by numerous irregular, at the utmost some dm wide veins of quartz with crystal plates of hematite and great rhomboedrons of a yellowish white, ferruginous carbonate (ankerite?). There also occur rather small veins consisting almost entirely of hematite crystals. In several veins there are seen red feldspar crystals, reaching a length of only some mm. Under the microscope they show a very fine striation; their index of refraction is considerably lower than that of the Canada balsam These characters indicate microcline.

The magnetite zone of Apollonia-Julia is accordingly rather similar to the parts of the great ore bodies that are most rich in apatite.

No wall rock is exposed, but quartz-porphyry with some apatite dikes outcrops some ten meters further westwards.

East of the magnetite zone there is a band of a massive feldspar rock, about 40 meters wide, fine-grained and of a red colour. Occasion-

ally there are seen in it quartz grains reaching a diameter of more than 1 mm, and small patches of hematite, but no large streaks as in the wall rock of Apollonia, to which this type is otherwise quite similar. It is cut by several quartz veins of an inconsiderable width.

Under the microscope the feldspar, which is rather highly coloured by red pigment, appears to be polysynthetically twinned. It occurs in nearly 1 mm long, isometric individuals with somewhat fringed borders. Quartz occurs in individuals reaching a size of up to 1 mm, in or between the feldspars. Many crystals have the usual rounded habit of quartz phenocrysts, others are much fringed, a regular intergrowth with the feldspar never occurs. Besides, the quartz occurs to a great extent in rounded grains reaching a diameter of only $0{,}_{10}$ to $0{,}_{15}$ mm, partly in aggregates between the feldspars, partly within the latter, which are occasionally quite larded with such inclusions. Lumps of hematite and single small crystals of zircon occur; muscovite is abundant, probably resulting from the alteration of the feldspar.

Even when not taking into account for the present the small quartz grains appearing to be of secondary development, the structure is very peculiar.

This red rock may be called the Rektor type porphyry. East of it there is a hematite ore zone, probably an immediate continuation of the exposures described above. The wall rock contains some sinuous lumps of bright hematite, which reach a length of some cm and are elongated in a north-southerly direction. A rapid transition exists between the wall rock and the ore; the intermediate phase consists of a reddish feldspar rock very rich in hematite, similar to the rock occurring in the hematite zone of Hildarius. A slide shows, that this is an altered phase of the red feldspar rock. The small grains of quartz are almost the chief constituents here; among them there are also seen single elongated grains of apatite ($0{,}_1$ to $0{,}_3$ mm in length) and some muscovite. Hematite occurs everywhere, in crystalline lumps or branching aggregates reaching about 1 mm in diameter.

The hematite ore is dense and bright blue, it is also very hard and has an uneven fracture. It occurs partly as streaks with a length of some cm, in brownish gray quartz, partly as larger lumps. Some meters from the foot (i. e. western) wall, angular fragments of the wall rock are occasionally enclosed, but there is seen little, if any, conglomeratic structure. Small veins of quartz with hematite and chalkosite cut the ore. They usually run in an east-westerly direction. The width of the hematite zone is here at least 5 meters. East of it there is syenite-porphyry. The hematite ore zone outcrops also in the claim of Julia, in the shape of a quartz mass, some meters wide and impregnated with hematite. East of it there are outcrops of syenite-porphyry.

Further northwards there is no exposure to be found for a distance of more than 150 meters, then there are excavations in the claim of Ansgarius and, after another 180 meters, those in Valerius. In these two claims the border of the quartz-porphyry is exposed nowhere, the magnetic conditions indicate, however, that the magnetite ore does not continue as far as here.

Claim of Ansgarius.

The excavations show, beginning from the west:

1. Feldspar-quartz-rock, belonging to the Rektor type, porphyritic (19 meters). Furthest west it consists of a white, very fine-grained quartz matrix, containing thickly tabular red feldspars about 1 cm in length with well reflecting cleavage planes, and besides small (1 to 3 mm in size) rounded grains of the same substance, now scattered throughout the quartz mass, now concentrated in lumps. The feldspar generally constitutes somewhat more than half the rock. Small patches of sericite with bunches of black tourmaline prisms in the centre are sometimes seen. Small quartz veins occur. More eastwards the rock shows a rather indistinct stratification marked by irregular, $0{,}_5$ to 4 cm wide streaks of almost dense hematite ore, in which single red feldspars and tourmaline bunches occur, besides small patches of hematite are seen here and there. Even the feldspar-quartz-mixture shows a rude separation in layers and in one place characters similar to cross-bedding.

2. Relatively pure hematite of the kind described above (1 meter).

3. Breccia of the same kind as 5 ($5{,}_8$ meters).

4. Covered ($8{,}_4$ meters).

5. Breccia (11 meters exposed). It consists chiefly of angular or fringed fragments of feldspar rocks, embedded in a matrix mostly consisting of finely crystalline hematite. The fragments reach a diameter from microscopic dimensions and up to some dm; their outlines are often diffuse. They are of a dark gray or red colour, the gray ones often having red borders. The grain is always very fine. The matrix consists now of almost pure hematite, now of a finely crystalline mixture of this mineral with apatite and quartz, often also of pure apatite, which especially borders the fragments. Occasionally the hematite is somewhat mixed with magnetite. Furthest east (for some meters) apatite is predominant. The fragments are often impregnated with hematite or with sericite, which nearly always contains beautiful »suns» often more than 1 cm in diame-

ter, of black tourmaline prisms. Both the fragments and the matrix are cut by numerous, often drusy veins, generally only some cm wide and never straight. Some of them consist of quartz, red feldspar, hematite in crystal plates and rhomboedrons of a carbonate, probably ankerite, others consist only of quartz or only of hematite. These feldspar-bearing veins are doubtless the ones called »rote Orthoklasgänge» by STUTZER [62], though it is not quite certain from his description that the occurrence visited by him is the one that we are now occupied with.

STUTZER has observed quartz-hematite veins cutting others, containing feldspar. The former are doubtless the youngest veins of the region.

Only a few meters north of this prospecting trench there is another, comprehending only the breccia zone. Within the most easterly 16 meters exposed it is very different from the other exposure (its easternmost

Fig. 55. Sericite with tourmaline »suns».
Breccia, claim of Ansgarius. Nat. size.

part excepted) as it consists of numerous, generally angular, fragments of the above mentioned dark brownish gray rock in a white or gray matrix of finely crystalline apatite mixed with some magnetite and hematite; these ore minerals are often gathered in small lumps. The whole is rather similar to the apatite dikes of the quartz-porphyry between Luossavaara and Nokutusjärvi. How much this breccia differs from the one occurring in the easternmost parts of the precedent trench is not so very easy to determine, as a prospecting pit is sunk in the southerly one, while in the northerly one the natural surface with its glacial striæ is intact.

East of these exposures of breccia the ground is covered for a long distance, it being consequently impossible to determine, what kind of rock lies immediately above the breccia, probably it is syenite-porphyry.

The microscopic examination of the rocks of these exposures shows the following. The groundmass of the *feldspar-quartz-rock* consists exclusively of quartz in rounded or irregularly polygonal grains about 0,1 mm in diameter and single small flakes of muscovite; an idiomorphic zircon crystal is occasionally seen. The optical properties of the feldspar cannot be determined on account of the great quantity of red pigment. There are often seen small patches of clear, broadly lamellated plagioclase in such a red feldspar; inclusions of apatite occasionally occur together with those of plagioclase, having their longer axis in the same direction as the latter. Some feldspars have straight

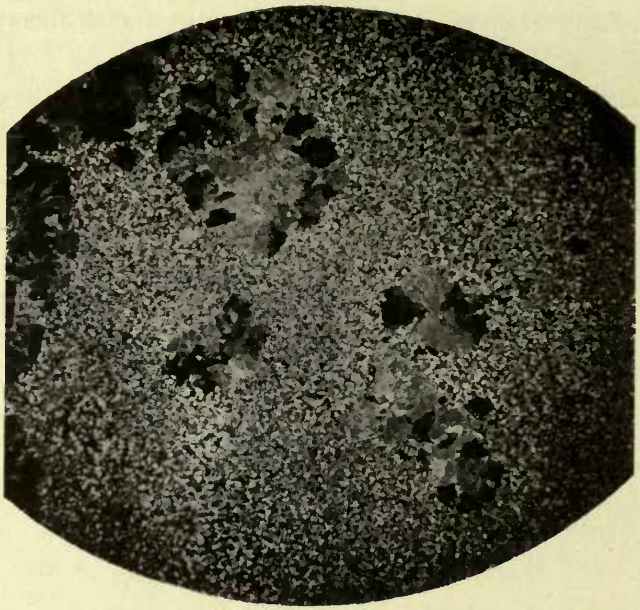

Fig. 56. Quartz-porphyry of the Rektor type, claim of Ansgarius. Nic. +. Magn. 14 times. Sphærulitic feldspars in a groundmass of irregularly polygonal quartz grains.

outlines, but most of them are surrounded by a scalloped sphærulitic border of varying width. Zircon crystals occur as inclusions. From these feldspars there are transitions to rounded or somewhat angular sphærulitic bodies, 1 or a few mm in diameter. When they are concentrated in clusters, small individuals of a limpid plagioclase are occasionally seen between them. A typical picture of such sphærulites and of the groundmass is seen in fig. 56. These sphærulites are optically positive.

Enclosed in the feldspars or free in the groundmass there occur quartz grains reaching a diameter of 0,3 to 0,6 mm and generally rounded, but often with fringed borders. The existence of a dark line somewhat inside the border indicates that these uneven outlines probably depend on a secondary enlargment. Such dust lines are evidently, at least generally, missing in the quartzes enclosed in the feldspars.

The sericite of the breccia contains fragments of red feldspars, in part it evidently replaces this mineral. The tourmaline is pleochroic with O = deep blue; E = pinkish; absorption O > E. It is generally rather well idiomorphic. On a crack in an individual there are seen some grains of baryte. Some thick prisms of apatite are embedded in the sericite felt.

A slide from *the westernmost part of the breccia* shows the following. Numerous feldspar crystals or fragments of crystals are enclosed in a matrix composed chiefly of quartz, apatite and hematite. The feldspar is red on account of much pigment. The individuals reach from a few tenths of a millimeter up to several mm in length, they have uneven and fringed borders. The feldspar substance is sometimes quite evidently in part replaced by lucid plagioclase, muscovite and quartz. In the slide is also seen a fragment of a porphyritic rock, with feldspar phenocrysts reaching a size of 1 to 2 mm in a groundmass of elongated individuals of the same mineral, having a length of 0,2 to 0,5 mm. Hematite is abundant in prickly lumps just as in some of the Hopukka rocks. All feldspar is red, the pigment increasing in quantity nearer the borders of the fragment. The quartz of the matrix occurs in irregular grains having a diameter of some tenths of a millimeter, often forming a mesostasis to the crystals of apatite. This mineral occurs in about the same quantity as the quartz in thick prisms reaching a length of up to 1,5 mm. Hematite is abundant in prickly lumps and branching aggregates of crystals. Muscovite is also present in rather great abundance.

There is evidently present here not only an interlacing of an eruptive rock (the porphyritic feldspar rock) by veins of hematite, quartz, apatite albite and muscovite, but also a replacing of the same rock by these minerals. The breccia is very similar to the one forming the foot wall of the hematite zone in the claim of Rektorn (see p. 170). It is probable that the isolated feldspars, which are so abundant in the breccia of Ansgarius, are remains of the same kind of rock as the larger fragments just described. They are quite similar to the phenocrysts of the latter. Especially remarkable is the petrographic similarity between the matrix and the apatite dikes both as regards those of the quartz-porphyry, and the few veins occurring in the syenitic rocks hitherto described. They are especially similar to the veins in the foot wall rock of the magnetite zone in Apollonia.

This resemblance is still more striking in *the easternmost part of the exposure* in Ansgarius, where the matrix consists chiefly of apatite. The fragments belong to the same porphyritic rock, composed of feldspar and hematite, as the largest fragment of the above described slide from the westernmost part of the breccia. The feldspar is to a great extent altered to muscovite, and also calcite and quartz occur here and there as secondary products. The veins consist principally of apatite in the usual shape of short prisms. Quartz occurs here and there, now as mesostasis, now with a tendency to idiomorphic development. The ore minerals are concentrated in patches. Small plates of muscovite lie between the apatite grains. Enclosed in a quartz-aggregate there are seen some crystals of ferruginous carbonate. This occurrence indicates a near relationship

between these apatite dikes and the drusy feldspar-quartz-hematite veins which also often contain crystals of the same carbonate mineral.

Summary. Furthest west in the exposures at Ansgarius there is quartz-porphyry rock of the Rektor type, highly silicified. East of it follows a narrow hematite zone and still further east a breccia, consisting mainly of fragments of syenite-porphyry in a matrix rich in apatite.

Claim of Valerius.

These exposures are located about 150 meters north of the precedent ones. The southernmost prospecting trench shows the following profile, beginning from the west.

1. Feldspar-quartz rock (Rektor type), similar to the easternmost parts of No. 1 in Ansgarius, but more rich in quartz and impregnated with hematite. At the border to the ore zone, the rock consists almost entirely of quartz. (4 meters exposed.)

2. Bright blue hematite ore, finely crystalline or dense, and exceedingly hard. Quartz occurs in great quantities, chiefly in irregular bed- or vein-like masses attaining a width of up to 7 dm, in rather small typical veins with or without hematite crystals and in rounded lumps. But it also occurs equally mixed with the hematite. Furthest east the ore is rather rich in finely distributed magnetite. (25 to 30 meters. The contacts are covered, and perhaps not well defined, a quite exact figure can therefore not be given.)

3. Breccia of the same kind as furthest west in Ansgarius, with a 1 meter wide band of hematite ore. (3 to 4 meters wide.)

4. Feldspar-quartz rock with alternating, scarcely 1 cm wide bands of quartz and of small sphærulitic grains of red feldspar. The banding is not very regular. (Only a few meters exposed).

Some 30 meters more to the north there are some excavations beginning very little further east than the precedent profile ends, they may therefore be regarded as a continuation of the latter. The rock exposed is feldspar-quartz rock without any sign of stratification. The feldspar occurs equally distributed in a subordinate quartz matrix. Small tourmaline-bearing patches of sericite occur. This rock is some 20 meters wide. East of this rock there outcrops an about 1 meter wide quartz mass rich in hematite, which seems to be a continuation of the hematite zone, last seen in Julia.

When comparing these exposures to those of Ansgarius we find in the first place that the westernmost rock is quite the same in both cases. But while there is only a little relatively pure ore in Ansgarius, a wide breccia zone with much hematite in its matrix existing on the contrary, a highly quartziferous zone plays the most important part in Valerius and the breccia is quite subordinate. This is with regard to the occurrence of ore. As to the barren rocks, in Valerius there seems to be no equivalence exposed to the syenite-porphyry forming the fragments in the eastern part of the breccia of Ansgarius.

In spite of the quartz masses occurring in the hematite ore, the latter seems to be much richer than in any other exposure south of lake Syväjärvi. An analysis of a hand specimen of ore without visible quartz, made by G. NYBLOM, shows the following:

SiO_2	8,04
Al_2O_3	0,39
Fe_2O_3	88,41
FeO	2,52
MnO	0,02
MgO	0,06
CaO	0,23
Na_2O	0,05
K_2O	0,29
H_2O	0,17
TiO_2	0,39
P_2O_5	0,002
S	0,02
	100,59

The TiO_2 content is rather striking, being almost as high as that of the magnetite ores of the region.

About 200 meters north-northeast (i. e. in the direction of strike) of the exposures in Valerius, in the *claim of Agneta*, highly quartziferous hematite ore is exposed after the removal of a 4 meters thick moraine. The uncovered area is very small, and it is perhaps only a large boulder.

Claim of Olof.

Another 200 meters further off, in the *claim of Olof*, there are outcrops and a small prospecting pit. Furthest westwards there is a feldspar-quartz rock, rather similar to the foot wall rock in Ansgarius and

Valerius and impregnated with hematite. It is exposed for a width of about 4 meters. Immediately east of it there is the hematite ore zone, being in this place about 15 meters wide. The ore is lean and interstratified with bands of white or gray quartz, in the latter there are seen numerous rounded, dark phenocrysts of the same mineral, reaching a size of about 1 mm. Fine-grained black ore, with some magnetite, and a scaly variety alternate with one another and with the quartz, but the bedding is very irregular and points of ore stick into the quartz bands at almost right angles to the plane of stratification. Within the ore there are also found areas of the foot wall rock, very rich in quartz and impregnated with hematite.

The foot wall rock is under the microscope rather similar to the one between the magnetite and the hematite zones on eastern Luossavaara (for instance in the claim of Rektorn) and belongs evidently to the Rektor type. It consists chiefly of albite feldspars, more than 1 mm in length, and quartz grains with a strong tendency to idiomorphic development. Between these constituents there is a quantitatively subordinate mosaic of small quartz grains of the common, irregularly polygonal shape.

A slide of the gray quartz shows the bulk of it to be a mosaic of irregularly polygonal grains of the size (about 0,1 mm) that is most common in the quartz masses of this group. The gray colour depends on an impregnation with ore minerals. The phenocrysts are quite similar to the quartz phenocrysts of the foot wall rock here and in Ansgarius, a dust line denotes that their irregular outlines probably are due to secondary enlargment, the original form having been more rounded.

East of the hematite ore there is a syenite-porphyry. Its contact with the ore is not exposed.

Some 10 meters further off there is a little prospecting pit in the ore zone. The latter is here a breccia, the matrix is lean, black, granular hematite, in which there are innumerable fragments of similar ore, plates of finely crystalline muscovite and especially angular or rounded lumps of white quartz, generally one or a few cm in diameter, besides there occur small patches of red feldspar, very often within the quartz lumps. Short curving bands of laminated hematite ore occur. The whole of it is cut by numerous quartz-hematite veins.

Under the microscope, the matrix appears to be a finely crystalline mixture of quartz, hematite and feldspar and small quantities of other minerals. The feldspar is »striped» and may reach a size of up to some mm. It is to a great extent replaced by quartz, in the shape of rounded or irregular grains, often being so numerous that the feldspar has the appearance of a sieve. This process of silicification evidently causes the development of quartzitic rocks. The hematite is often lucid, with a deep red colour. Sericite flakes occur here and there. Baryte is common and occurs in irregular, elongated individuals having

a length of up to 1 mm. Partly it seems to replace feldspar. In one place it is seen together with quartz filling a fissure in the rock. There are also present crystals of zircon and irregular grains of orthite. Quartz phenocrysts with rather regular outlines are also sometimes seen.

The quartz fragments consist almost exclusively of polygonal grains having a diameter of about 0,1 mm, besides they often contain some sieve-like feldspars, baryte and sericite.

A great part of the quartz occurring in this breccia-like rock is evidently of secondary origin, replacing feldspar. The original mass has therefore been composed as an igneous rock, but it is now impossible to ascertain whether it has been a flow-breccia or a tuff. It certainly belongs to the Rektor type.

Exposures between Olof and lake Nokutusjärvi.

For a distance of about 300 meters from the last-mentioned exposure there are numerous outcrops and some prospecting excavations. Apatite dikes are very common in the quartz-porphyry especially in this region and immediately north of it. It (viz. the quartz-porphyry) is right up to its eastern boundary interwoven with such dikes, some of which are not sharply defined towards the rock, contrary to what is the case somewhat further west. The whole is rather similar to the phenomena in the foot wall rock of the magnetite ore of Apollonia. As there, the porphyry is to a rather great extent altered and unlike the common one.

Under the microscope it shows strong signs of chemical alteration, but has kept sufficient primary characters to be identified with the quartz-porphyry. The most common secondary minerals are quartz, calcite and sericite, sometimes also tourmaline. Hematite and pyrite, occurring separately or in lamellar intergrowth, also seem to belong to the same period. The quartz occurs in irregular grains, often lobate and branching. This is especially the case when it partly replaces the feldspar phenocrysts. The calcite often forms rather regular crystals, but it is scarcely to be doubted that it belongs to the same period of formation as the quartz. The sericite, this common secondary mineral, is as usual present in small flakes. The tourmaline often forms skeleton individuals. Its pleochroism is $O =$ brownish green; $E =$ pinkish; absorption $O > E$. The metamorphism seems to have befallen phenocrysts and groundmass in about the same degree.

One apatite dike is surrounded by a rock very rich in the same mineral, partly crystallized in small cavities. The examination of a slide shows the feldspar phenocrysts of the quartz porphyry, somewhat altered; the groundmass must be recrystallized, as it principally consists of small irregular grains of quartz with patches of red feldspar substance. Apatite is abundant in this groundmass, occurring in elongated allotriomorphic individuals generally having a length of 0,5 to 1 mm. Calcite, muscovite and hematite occur here and there. The question is now: is this abundance of apatite a primary character of the rock,

the vein then being a segregation in situ, or is it of secondary origin? As the rock shows so many signs of chemical alteration, the latter alternative seems to be most probable.

The Rektor type rock composing the foot wall in Olof seems to end rather soon northwards. The hematite zone occurs on the whole in the same manner as in the two last described exposures. It is brecciated, containing angular fragments of quartz and hematite ore and slabs of sericite. Winding bands of white quartz occur as well as smaller ones of calcite.

The hanging wall rock is a dense quartzitic rock of grayish white colour, resembling a hälleflinta. It is not distinctly stratified. The examination of a slide shows it to consist almost exclusively of quartz with some baryte, hematite, sericite and zircon. Some quartz grains reach a size of some tenths of a millimeter and have a dust rim. The bulk is in its structure similar to the other dense quartzitic rocks.

Some 20 meters east of the ore zone there occurs in this rocks lean hematite ore, which is probably an impregnation in a phase of the quartzitic rock uncommonly rich in sericite. This ore is very little extended, north and south of the exposed part it may perhaps cohere with the main zone. East of the quartzite-ore zone there is syenite-porphyry.

Further north, the ore zone chiefly consists of a gray quartz rock, the parallel-structure of which is marked by thin layers rich in sericite. Some, a few dm long areas, have been somewhat shifted into the rest of the mass but with no sharply defined contact. This very peculiar phenomenon cannot be explained by any kind of folding.

The microscopic examination of the rock shows a quartzitic matrix with some hematite, and in some layers much sericite, besides, single crystals of zircon. In this groundmass there are numerous quartz phenocrysts having a diameter of some tenths of a millimeter. They are generally somewhat rounded and have even outlines. When this is not the case there is often just inside the border a dark streak enclosing a more regular area.

The rock is evidently a highly silicified quartz-porphyry-tuff.

The most northerly exposure at the southern side of lake Nokutusjärvi is located somewhat more than 1200 meters from the excavations of Valerius on Luossavaara, which, as may be remembered, are the most northerly ones of this mountain.

The Nokutusvaara ore field.

The main part of this ore field is situated between the lakes Nokutusjärvi and Syväjärvi, only a small part being located north of the latter. A few quite small outcrops of ore and rock occur, the greatest part of the area being covered with moraine, generally of little thickness. The ore is exposed in many prospecting excavations, in which sometimes the wall rock is also visible. These excavations have been made at several places, where the magnetic inclination has indicated the existence of ore in great quantity; the geological mode of occurrence of the ore bodies is consequently, in spite of these excavations, very little known.

On the accompanying sketch map all the exposures are indicated in the same way as on the map of the Hopukka porphyries.

When first regarding the region south of lake Syväjärvi, we find there furthest west a wide zone of magnetite ore. East of it there are a hematite-bearing quartzite zone, and quartz-porphyries, all little exposed.

As starting-point for the description we take the exposures *No. 4*, a row of prospecting trenches cut at almost right angles to the direction of strike, which is the most complete profile existing within the ore field.

We begin in the west:

1. Fine-grained magnetite ore very rich in apatite (23 meters exposed). Furthest west the ore is quite massive and consists of an even mixture of magnetite and apatite, sometimes also of some carbonate. More to the east it is banded by varying layers of pure apatite and of ore rich in apatite. Folding on a small scale is very often seen and seems to have befallen only some layers but not those lying above and below. There also occur larger concentrations of apatite, containing lenses of magnetite. The ore is sometimes filled with white elongated patches of apatite, 1—3 mm in diameter. Pure ore has a bluish colour. Here and there quartz and small patches of malachite are seen. Quartz and ankerite[1] occur in irregular streaks or in more sharply defined veins some cm wide.

A slide of ore with apatite spots shows the following. The magnetite is idiomorphic towards the apatite, which is abundant even outside the spots. In the latter, the apatite occurs in prisms having a length of about 0,1 mm, parallel to one another. There are also present here and there in the slide, clear,

[1] Ankerite is here used for ferruginous carbonate.

broadly lamellated albite in grains reaching a diameter of up to 0,2 mm, and some chlorite.

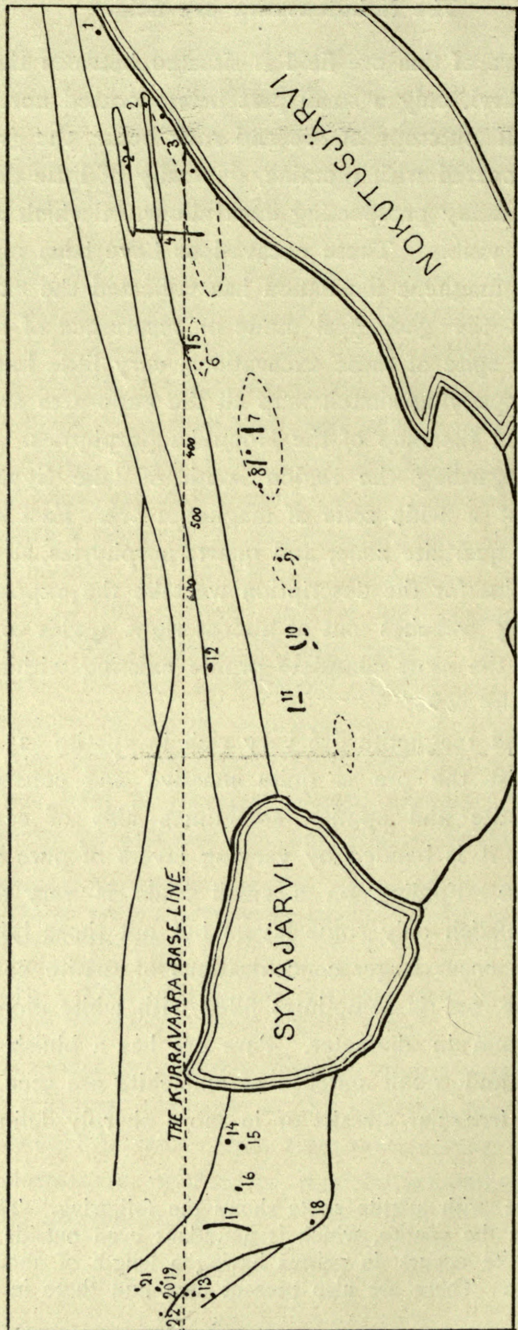

Fig. 57. Map showing distribution of outcrops, Nokutusvaara ore field. Scale 1 : 10000.

2. (Some meters exposed.) Fine-grained rock, partly massive and of reddish gray colour, partly rich in dark gray sericite. These two types very suddenly pass into one another, the latter evidently being only an altered phase of the former. Nodule-like aggregates of magnetite are common and reach a diameter of up to 1 cm; besides there occur schlieren containing great quantities of the same mineral in fine distribution. Patches of malachite are seen here and there. The rock is interwoven with veins, some of which are 1 dm wide. They consist of quartz, ankerite in crystals having a length of some cm, hematite, orthite, bornite, malachite, some magnetite and probably also apatite.

A slide of the reddish phase shows it to be a syenite-porphyry, mostly consisting of feldspar in elongated individuals reaching a size of 0,3 to 0,7 mm. It is very rich in red pigment, which renders the examination of its optical properties difficult. A fine striation is, however, visible in some individuals. Magnetite is much less abundant, occurring in idiomorphic crystals or aggregates of crystals, besides there also occurs zircon. Together with the secondary muscovite (sericite) there are seen bunches of tourmaline, and quartz. The tourmaline has O = olive green; E = reddish purple; absorption O > E. The nodules are often rounded. The feldspars are sometimes tangentially arranged around them. The mineral constituents are magnetite (predominant), apatite, quartz, albite, carbonate; tourmaline and sericite also occur, being probably secondary in relation to the others. Feldspars are sometimes common to a nodule and the surrounding rock. In some nodules short apatite prisms occur, lying poikilitically in quartz or in albite in the same way as is common in apatite dikes and in the ores related to them.

Another slide of a phase rich in magnetite shows the following. Half the volume consists of magnetite in prickly lumps, generally having a diameter of 0,2 to 2 mm. The mass between them is in places evidently a porphyritic rock with albite phenocrysts, reaching a diameter of 0,5 to 6 mm, in a fine-grained groundmass of sinuous grains of the same mineral. Calcite, quartz, muscovite and biotite sometimes replace the feldspar mass altogether.

3. Covered, 5 meters.

4. Rock, mostly consisting of sericite with some magnetite (5 meters exposed).

5. Covered, 15,5 meters.

6. Gray schistose rock (0,5 meters exposed).

Under the microscope it appears to consist chiefly of quartz in small grains and of much calcite. Besides there occur some albite, muscovite, biotite and magnetite.

7. Covered, 8 meters.

8. (17 meters exposed). Dense, massive rock of a pinkish colour, breccia-like on account of numerous fine veins of lean hematite ore. These veins are often quantitatively predominant, the rock then having the cha-

racter of a hematite ore with angular rock fragments. Thus a transition takes place, to

9. ($25{,}5$ meters exposed). Hematite ore, very lean. It is to the greatest part filled with often sinuous fragments of gray quartz or of hematite, sometimes also of the just mentioned red rock. Some hematite fragments contain amygdules of quartz. As a rule, the fragments reach only a few cm in length.

10. ($1{,}5$ meters exposed). Rock like 8, interwoven with narrow hematite veins rich in apatite.

The rocks 8 to 10 accordingly constitute a continuous series. At the description of their microscopic characters it would be most appropriate to begin with 10. This is a quartz-porphyry with phenocrysts of feldspar and of quartz. The former are very numerous, but very small, reaching a size of only one or a few mm. They are generally somewhat rounded, never quite idiomorphic. To a great extent they are distinctly »striped», but spots with lower birefringence indicate that small quantities of potash-feldspar are also present. The quartz phenocrysts are less common than the feldspars and about as large as the latter, they have very irregular outlines but generally also a dust line surrounding a more regular area. The groundmass is made up of feldspar and quartz in about the same quantities. The structure does not seem to be primary, the quartz occurs in branching areas, partly composed of polygonal grains. The veins are seldom sharply defined and have the appearance of zones of impregnation, including areas of unaltered rock. Their minerals are hematite, apatite, quartz, albite, calcite, muscovite and zircon. The apatite occurs in elongated grains about $0{,}1$ mm in length, the hematite in somewhat larger crystalline lumps. The quartz forms polygonal grains of varying sizes, it is younger than the precedent ones. The albite occurs rather sparingly, it is lucid and broadly lamellated. Zircon is present in abundance.

A slide from the ore zone (9), containing a quartz fragment and surrounding matrix, shows the following. The matrix consists chiefly of finely crystalline hematite and of quartz in small, often polygonal grains. Besides there occur larger quartz grains, quite similar to the phenocrysts of the above described porphyry. Clear albite in individuals reaching a size of $0{,}1$ to $0{,}2$ mm is very common, as well as calcite; orthite, zircon and muscovite are seen here and there. The fragment consists of irregular polygonal quartz grains about $0{,}1$ mm in length, and some calcite and baryte. Its outlines are very sinuous and not those of a waterworn pebble. Similar small fragments are seen here and there in the matrix. Often they are not very sharply defined.

A slide of the breccia (8) shows that the red fragments have originally been quite similar to the quartz-porphyry (10). They are, however, to a great extent replaced by a mosaic of quartz grains, altogether resembling the above described quartz fragment of 9. This quartz mass is often seen in patches in the normal groundmass and often includes rests of feldspars. (See fig. 58.) Besides there occur some muscovite and calcite. The matrix consists of much altered parts of the same porphyry, hematite and apatite being the most important minerals. For the rest it is quite similar to the veins of 10.

Both upwards and downwards the hematite ore accordingly passes into systems of veins and zones of impregnation in the quartz-porphyry.

It is very probable that also the middle (9) is of a similar kind, though the alteration has there been very radical. There has perhaps been present a flow-breccia, or some other form of fragmental rock, offering greater possibilities to the metamorphism, which has affected some parts more than others.

No. 3 comprises some outcrops of magnetite ore, most of them being found at the shore of Nokutusjärvi. The ore is fine-grained or dense, of a dark bluish colour. It contains large nests and lumps of finely cry-

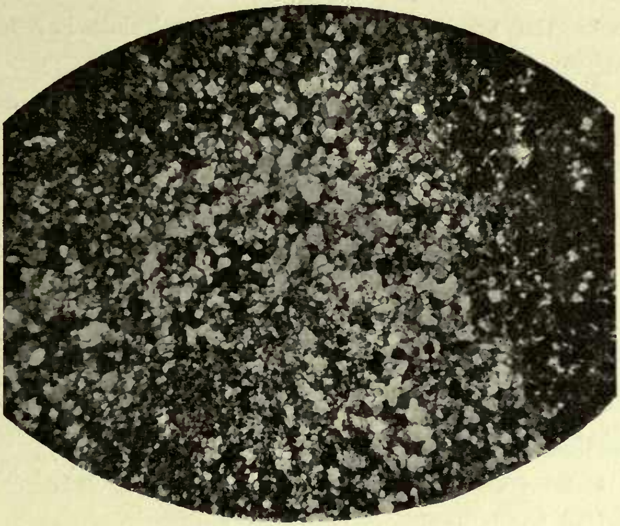

Fig. 58. Quartz-porphyry fragment in hematite ore, 8 of loc. 4, ore field of Nokutusvaara. Nic. +. Magn. 35 times. The fragment consists chiefly of new-formed polygonal quartz grains (the typical silicification structure), but small patches of the original, more fine-grained groundmass are still seen. To the left a little of the »ore» is seen.

stalline apatite with some quartz, often concentrated in drusy masses. There are also seen crystal plates of hematite. A continuation of the magnetite zone of No. 4 is evidently at hand here. In the southernmost outcrop there is seen a rock very rich in magnetite resembling 2 of No. 4.

A slide of an apatite concentration in the ore shows the following. The apatite prisms reach a length of up to a few mm. As usual they contain numerous plates of red hematite. The spaces between the apatite individuals are occupied by quartz in rather small polygonal grains. Some calcite is seen, it is idiomorphic towards the quartz. Moreover there are seen zircon, muscovite, magnetite and hematite.

The isolated exposure 40 meters south of No. 4 is a rock similar to 2 of this profile.

No. 2. Two groups of outcrops of the reddish quartz-porphyry occurring furthest east in No. 4. The rock is very homogeneous. It contains some small grains of chalkosite and, especially in the more southerly outcrop, some finely distributed hematite. It is cut by some veins reaching a width of up to 15 cm, some consisting of magnetite, hematite, apatite and quartz, others being exclusively made up of apatite.

Even under the microscope the rock is quite similar to that of No. 4, but it lacks the small veins. The examined slide is from the more northerly outcrops.

This quartz-porphyry is accordingly structurally different from the great mass Kiirunavaara-Nokutusjärvi, which occupies a lower level, it is also more siliceous. It is quite identical with that found by ZENZÉN between Luossavaara and Haukivaara. This type of porphyry may be called the Nokutus type.

No. 1 is a small exposure of hematite ore, similar to that of No. 4.

No. 5. Furthest west there is magnetite ore, about 15 meters exposed. It is finely crystalline and rich in apatite, equally distributed in the magnetite mass. East of the ore there follows a dark schistose rock rich in magnetite, the contact is covered. The width of this rock amounts to only about 1 meter. Next to it there is a similar rock, which is, however, almost free from magnetite (1 meter exposed).

No. 6. Finely crystalline and hard ore, magnetite with some hematite. Within it there occur some rather narrow bands of a schistose rock, mostly consisting of rather coarsely crystalline calcite with some biotite. It is uncertain whether these bands have any very great extent in the direction of strike. The microscopic examination shows, beside the minerals already mentioned, small quartz grains, gathered in streaks and patches, and some magnetite.

Numerous irregular veins occur. They consist of quartz, hematite, and ankerite in rhomboedrons having a length of several cm. The ankerite is younger than the hematite. There also occur veins consisting exclusively of hematite or of calcite.

No. 7. Furthest west there is massive magnetite ore, passing into ore with stripes of apatite. 7 meters from the western end there is a chlorite schist, 3 meters wide, with streaks of apatite. The rest of the profile, about 30 meters, consists of magnetite ore very rich in apatite,

which mineral partly occurs in big, irregular concentrations, and is partly more equally distributed.

No. 8. In these excavations the ore is rich in apatite and contains bands of chlorite rock.

No. 9. Ore rich in apatite.

No. 10. In the easternmost excavation there is magnetite ore, often with streaks of apatite. At its eastern end there appears a somewhat schistose rock rich in magnetite. The other exposures show an irregular mixture of rock and ore. The rock is massive and of a gray colour, with gray feldspar phenocrysts reaching a length of some mm. The magnetite ore, which is rich in apatite, occurs as irregular schliere-like bodies evidently being magmatic segregations from the porphyry.

The microscopic examination shows the rock to be rather similar to the syenite-porphyry south of Nokutusjärvi, west of the claims of Enok, Abel etc. The phenocrysts show broadly rectangular sections with a rather good idiomorphism, they are broadly lamellated, but also »striped» at the borders. The penetration at right angles is also seen. The index of refraction is about the same as that of the Canada balsam. The groundmass mostly consists of feldspars of the same kind, broadly rectangular and reaching a length of some tenths of a millimeter. Magnetite is present in abundance in the shape of aggregates of crystals; some titanite and biotite are also seen.

No. 11. Also in these exposures there is a mixture of ore and porphyry, the former being, as a rule, predominant. It encloses numerous, generally rounded lumps of barren rock, generally about some cm in diameter. They are sometimes orbicular, being gray in the centre and white in the periphery, the outline between these two parts is as sharp as the outer one towards the ore mass.

One slide shows, beside magnetite, lucid albite constituting almost half the volume of the »ore». It occurs in rectangular sections, varying in length between 0,3 and 0,8 mm, and in width between 0,15 and 0,40 mm. The structure is characterized by the magnetite's being concentrated between the feldspars, but being idiomorphic in detail. It is accordingly similar to the one described on p. 37, but is more strongly pronounced. The magnetite is in places concentrated in rather big lumps. Besides, there occur rather much apatite, isolated patches of biotite and chlorite and some grains probably of altered titanite. In the slide there is seen a small area of the white rock. It consists principally of albite in small sinuous grains, besides, of apatite in crystals reaching a size of up to 1 mm, and of some magnetite.

This rock is thus in its composition similar to some phases of the magnetite-syenitic group occurring some hundred meters further west. Structurally it chiefly resembles, as is already mentioned, a kind of nodules in the foot wall rocks of Kiirunavaara.

No. 12 is an outcrop of the hematite zone, resembling the one of No. 4.

North of lake Syväjärvi we do not meet with the magnetite zone again. There is on the contrary a red quartz-porphyry under the hematite zone. North of this porphyry the syenitic rocks of Hopukka occur. East of the hematite zone there is the gray, schistose porphyry of the Hauki complex.

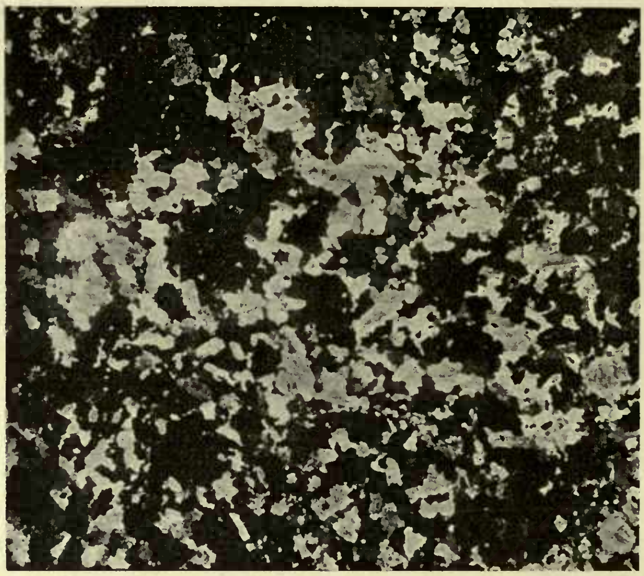

Fig. 59. Magnetite ore from loc. 11, ore field of Nokutusvaara. Nic. +. Magn. 14 times. Albite feldspars (the striation is often visible) in a groundmass of magnetite.

No. 13. A series of prospecting excavations, showing a porphyritic rock with rectangular feldspar phenocrysts, some mm long, in an almost dense groundmass of a bright red colour. The rock is richly impregnated with hematite in streaks and patches.

The examination of a slide shows that the rock in its original character has been almost totally similar to some phases of the great quartz-porphyry mass of Kiirunavaara—Nokutusjärvi. The phenocrysts are partly rather well idiomorphic. Some are finely striated. The groundmass is rich in quartz and contains much red pigment, which is the cause of the high colour. Small zircon crystals are common. The structure is probably not primary. In the easternmost outcrop there are present nodule-like aggregates of feldspar of the same kind as is seen here and there in the quartz-porphyry more to the south. The rock is much altered. The phenocrysts contain muscovite and sericite, and some of them are partly replaced by a mosaic of quartz grains. Others, among them one having a diameter of 7 mm, have in the centre a mixture of calcite, muscovite, quartz,

albite and hematite (in crystal plates), evidently all of them products of alteration. Also the groundmass has strong marks of metamorphism. It is rich in muscovite and in aggregates of quartz grains or of compositions similar to those occurring in the phenocrysts. Small tourmalines are also seen, with O = bluish olive green; E = pinkish; absorption O > E.

As the rock consequently in both primary and secondary characters is quite similar to the parts of the quartz-porphyry lying immediately underneath the hematite ore zone between Luossavaara and Nokutusjärvi, there are reasons for supposing these occurrences of quartz-porphyry to be formed at the same time and perhaps even coherent.[1]

No. 14 is a small prospecting pit in hematite ore. The latter is scaly, poor in magnetite and is rather similar to that of No. 4. Small cracks are filled with calcite and hematite. Sericite bands having a width of some cm occur, they stand almost vertically, and have very irregular outlines. Massive quartz, gray on account of high magnetite content, occurs in vertical bands with a width of up to $0{,}5$ meters.

No. 15 is a small outcrop of dark gray rock, rich in magnetite.

No. 16 comprises some small outcrops of hematite ore of the kind described above.

No. 17. This crooked prospecting trench measures along the curve about 80 meters. Furthest west there occurs a grayish white, little schistose, quartzitic rock, rich in sericite. (Some meters exposed.)

A slide shows the following. The rock consists of quartz in small grains much sericite and some hematite. The individuals of the latter two minerals are rudely parallel to one another. Further on there occurs single quartz phenocrysts having a diameter of up to 1 mm, and small crystals of zircon.

Next to this rock there follows the hematite ore zone with a width of about 60 meters in the profile line. As the latter goes obliquely towards the strike, the actual thickness is much less. The ore is finely scaly and contains great lumps of white or grayish quartz, generally of a rounded shape. There also occur bands of massive dark gray quartz and of a schistose rock rich in quartz and mica.

A slide of relatively rich ore shows that also the latter contains much quartz in small grains. Some areas consist almost exclusively of quartz, macroscopically they must evidently appear as inclusions of quartzite in the ore. Beside these small quartzes numerous phenocrysts of the same mineral are seen, quite similar to those of the quartz-porphyry exposed in Ns. 2 and 4 near Nokutusjärvi. Calcite is abundant, as well as orthite, the latter appearing in short prisms

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[1] As this rock, however, is not exposed between Nokutusjärvi and Syväjärvi, the writer has judged it most appropriate not to mark it there on the map.

with tendency to idiomorphic development. Muscovite and zircon are more subordinate.

East of this ore exposure the rocks are covered for about 10 meters, and then there is a massive, almost black quartz-magnetite rock, 3 meters wide.

No. 18 includes a few small outcrops of similar hematite ore.

No. 19. Fine-grained hematite ore, very rich in quartz and containing fragments of a reddish rock.

The microscopic examination shows a mosaic of polygonal quartz grains with hematite and up to a few mm large feldspars. The latter are to a great extent altered to muscovite, and hematite occurs in them in the same way as in the quartz mass. Their nature cannot be determined with certainty, but they are probably albite as the refraction is somewhat lower than that of the Canada balsam, and lamination is sometimes visible.

No. 20. Outcrop of a fine-grained, red feldspar rock, richely impregnated with hematite.

A slide shows the rock to be very similar to the Rektor type. It consists of albites one or a few mm in length, much altered to muscovite. Between them there is a mosaic of quartz with hematite, this mixture partly replaces the feldspar substance. Apatite is seen here and there, zircon is more rare.

No. 21 is a small outcrop of hematite ore.

No. 22. Outcrop of a rock similar to the above. Even under the microscope the similarity is great, but the phase in question is much more silicified than that of No. 20.

Summary.

The easternmost parts of the quartz-porphyry are generally interwoven with apatite veins and show traces of often strong metamorphism, which has resulted in the development of quartz, calcite, hematite, tourmaline, albite and sericite.

Immediately east of the quartz-porphyry there are the Rektor magnetite ores. These ores are very rich in apatite. By their content of albite, quartz and carbonate, they are also akin to the apatite veins. They differ from the main ores of the district chiefly by containing these minerals. The same is true of the magnetite ores in the southern part of the Nokutusvaara ore field. More to the north within the same field, the ores are evidently products of magmatic differentiation in a syenite-porphyry.

On Luossavaara there follows east of the magnetite ore the Rektor type porphyry. This rock is, at least to the greatest part, a tuff, but part of it may perhaps be a lava rock. In all cases it is a superficial rock. It has suffered silicification in a still higher degree than the quartz-porphyry.

The details of the mode of occurrence of the highly quartziferous hematite zone which is almost restricted to the claim of Valerius and is perhaps situated between two different beds of the Rektor porphyry, are not known, nor the extension of the tourmaline-bearing breccia of Ansgarius.

The main hematite zone is probably coherent from Kiruna to Hopukka, but its character is rather varying. Furthest south it is most similar to a quartz-porphyry tuff, very rich in hematite. Immediately north of Luossavaara the quartz and hematite mass replaces the Rektor porphyry, and more close to Nokutusjärvi its nature is almost the same. Between Nokutusjärvi and Syväjärvi it is partly an impregnation in the quartz-porphyry of the Nokutus type, but north of the last mentioned lake it has again the same character as south of Nokutusjärvi, also here partly replacing a feldspar rock.

In its mineralogical composition this quartziferous hematite ore is characterized by the presence of calcite, baryte, orthite, sericite and zircon, sometimes also by the abundance of apatite.

The strong metamorphism that has befallen all the rocks of this group more or less, must evidently be ascribed to a volcanic after-action, consisting in the emanation of gaseous compounds or hot watery solutions. Some of the latter may perhaps have been of almost magmatic character. The most important results of this fumarolic action is the thorough silicification of some rocks and the formation of the hematite ores.

As appears from the precedent description, the hematite has to the greatest part evidently developed through these processes. Its mode of occurrence in the quartz-porphyry of Nokutusvaara is very interesting. Part of the ores may perhaps have been deposited as a chemical precipitate, but even this mode of origin must be regarded as a post-volcanic process, as the iron very probably has appeared as gaseous emanations or as hot solutions.

For information about the hematite ores of the rest of the Hauki complex, which are very similar to those described abore, but often show distinct sedimentary characters, I must refer the reader to the papers in preparation by LUNDBOHM and ZENZÉN.

THE TUOLLUVAARA DISTRICT.

Distribution of Exposures.[1] General Survey.

This porphyry district is at least as great as the western one. It extends nearly as far north as that and outcrops much further south. Its eastern border cannot be quite exactly determined as the relations between the metamorphic rocks occurring there and the porphyries are not very well known. The most important exposures are three groups: Mount Sakaravaara furthest north, Tuolluvaara Hill with the only workable ore deposit of the district, nearly 4 kilometers south of Sakaravaara, and Mount Vahåive 8 kilometers further south. There also occur a few small outcrops between Haukivaara and Tuolluvaara, along the rivulets Luossajoki and Rotsejoki and in some other places.

The district in question is separated from the western one by the Hauki complex, whose youngest rock, as may be remembered, is a quartzitic sandstone. At Luossajoki the width of this complex may perhaps amount to 600 meters at the utmost. It is exposed for a width of about 200 meters, and about 2 kilometers further south it ceases altogether. It is a pity that no exposures render the study of the border between the different porphyry districts possible here. East of the quartzite there are metamorphic femic rocks, amphibolites and porphyrites. This zone is at Luossajoki about 70 meters wide. In the rest of the district there occur reddish quartz-bearing porphyries and, less abundantly, syenite-porphyries and porphyrites.

The exposures being so few and scattered, it is very difficult to give a detailed statement of the geology of the district. The following description is therefore concentrated on the two greater groups of exposures within the writer's field of work in this district, Sakaravaara and Tuolluvaara.

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[1] These areas are shown on the survey map of the whole Kiruna region, in a scale of 1 : 100000, which accompanies »View of the geology of the Kiruna district» by HJ. LUNDBOHM, in the guide for the Kiruna excursions during the XI. international congress.

Sakaravaara.

Exposures and kinds of rock.

The mountain forms an extended plateau; this is mostly covered, but on its northeastern side there are innumerable outcrops of a quartz-porphyry (with quartz phenocrysts).

The syenite-porphyries occupy the northeastern slope nearly right up to the porphyry of the plateau, but at a distance of about 20 meters from this border there occurs a band, 15—20 meters wide, of quartz-porphyry, not quite similar to that already mentioned. From morainic boulders it seems rather probable, that this band and the upper one of syenite-porphyry bend to the east around the mountain, indicating that the porphyries form almost horizontal beds. Further there is a small quartz-porphyry area northwest of the valley (Sakaradalen), which extends in a north-northeasterly direction through the syenite-porphyry area and the southern wall of which is an almost vertical precipice, 6 to 8 meters high.

North of the valley there is an isolated outcrop of porphyrite.

Porphyrite.

This is a dark rock, most similar to an amphibolite but the microscopic examination shows that it is probably an altered porphyrite, with small, badly idiomorphic plagioclase phenocrysts in a groundmass of isometric grains of the same mineral, reaching a size of about 0,1 mm, and bluish green hornblende in abundance, some magnetite and biotite. The refraction of the feldspar is considerably higher than that of the Canada balsam, which indicates a very basic andesine, nearly labradorite.

Syenite-porphyries.

Macroscopic characters.

Around the Sakara Valley these rocks are highly variable. Northwest of the valley they have a brownish red or gray colour, the groundmass is very fine-grained and the feldspar phenocrysts reach a length of some mm. The differently coloured phases alternate very suddenly with one another in a schlieric manner. The rock is often interwoven with nests and strings reaching a width of up to some cm and consisting of calcite, siderite, hematite, biotite, muscovite and quartz, sometimes also with radial aggregates of orthite. The calcite is the most common of these minerals. It weathers more quickly than the silicate rock; on a weathered surface, the porphyry accordingly has almost the appearance of a breccia.

In the southeastern wall of the valley there are partly similar rocks, principally gray or reddish porphyries with numerous feldspar phenocrysts reaching a size of up to 1 cm in diameter. They are rather like some of the foot wall rocks of Kiirunavaara. They are in places rich in finely distributed biotite, and by this a transition is made to a granular rock consisting of scapolite and biotite. This phase occurs as streaks and lumps in the normal porphyry.

A great part of the rocks on this side of the valley are still more similar to those outcropping on the other side. A dark gray, very fine-grained phase containing numerous irregular nodules and strings of calcite and biotite or sometimes hornblende nodules with some pyrite, is widely distributed, especially higher up the slope. In these outcrops there is a sudden transition from the normal rock to a granular aggregate of scapolite and biotite, which forms irregular lenses reaching a length of some meters and elongated almost in the direction of the valley.

A little further away from the valley the rock is free from nodules and is not altered to scapolite, but has otherwise the same appearance.

More close to the narrow band of quartz-porphyry the rock is very similar to the last mentioned phase. Nodules of quartz are common in its southernmost parts, and fine strings of calcite and biotite are seen here and there. In some places a reddish-brown garnet is present in abundance in individuals reaching a size of up to 1 cm in diameter. There sometimes appears a thin, but irregular stratification, a weak

schistosity always causing the outcrops to be elongated in the direction of the band. A small vein of quartz with some hematite and bornite cuts the rock.

Microscopic characters.

The reddish gray rocks, which are most common around the valley, show the following characters. The feldspar phenocrysts are acid plagioclase, polysynthetically twinned, often »striped», and often also with some cross- bars according to the pericline law. A system of cleavage cracks runs at right angles to the albite lamination. They are rather well idiomorphic and only little altered, only occasionally they contain some biotite and calcite, sometimes also tourmaline (O = olive green; E = pinkish, absorption O > E.)

The groundmass consists chiefly of clear albite feldspar in finely laminated, list-shaped individuals reaching a length of 0,1 to 0,2 mm, often trachytoidally arranged. Here and there more coarse-grained patches occur, containing also quartz, calcite, olive brown biotite and sometimes also microcline. Among the dark constituents the magnetite is the most important one, it often makes up about 5 per cent of the groundmass. It occurs partly finely distributed among the feldspars, partly in somewhat larger grains, filling the spaces between them. Small plates of biotite are often rather abundant. Apatite and zircon are also common, quartz is rather often present in some slides in the shape of small isometric grains. Calcite is often abundant, and tourmaline (with the pleochroism stated above) occasionally occurs in small prisms. There have been observed individuals of scapolite with a length of up to 1 mm, but outside the totally scapolitized areas this mineral seems to be rather rare.

A slide of a red variety from the southeastern wall of the valley shows some different characters and stands between the above described rocks and the quartz-porphyries. The phenocrysts consist partly only of »striped» albite with single pericline lamellæ, partly of a coarse microperthitic intergrowth of microcline and albite. They are rather well idiomorphic, often composed of several individuals. Skeleton crystals of biotite often occupy the greater part of a phenocryst, it is generally greatly altered to chlorite; otherwise few inclusions are seen, mostly magnetite. The groundmass is fine-grained, microgranitic and rich in quartz. Its feldspar is partly albite, partly microcline. Magnetite is present in abundance, in small grains without very sharp crystal outlines. Biotite and apatite are less common. Here and there more coarse-grained patches occur, in which even the magnetite is present in rather large lumps.

The gray rock higher up the western wall of the valley contains few feldspar phenocrysts. They reach a length of some mm and are rather broadly lamellated. The groundmass is very rich in dark minerals. The feldspar is quite similar to that of the above described rocks free from quartz, the refraction being almost similar to that of the Canada balsam. Consequently it is oligoclase-albite. Magnetite is abundant and occurs in grains reaching a size of about 0,1 mm in diameter. A weakly pleochroic, pale brown biotite is most similar to it as regards quantity, it occurs in plates reaching a size of 0,1 to 0,3 mm. Hornblende is almost as abundant and has the shape of individuals elongated parallel to the c axis and reaching a size of 0,1 to 0,5 mm. Its pleochroism is: $\mathfrak{a}$ = yellowish; $\mathfrak{b}$ = brownish green; $\mathfrak{c}$ = bluish green: absorption $\mathfrak{b} = \mathfrak{c} > \mathfrak{a}$. The angle $\mathfrak{c} : c$ is at least 19°; $\mathfrak{b} = b$. The optical character is positive. Titanite is common, if also less abundant than the above mentioned minerals. It forms small grains,

rounded or with a tendency to idiomorphism, never skeletons. Scapolite occurs here and there in individuals reaching a length of up to 2 mm.

The examination of the scapolite-biotite rock occurring as lenses in this gray porphyry shows the following. The scapolite forms the main part of the rock, occurring in sinuous individuals, reaching a size of 1 or a few mm. (See fig. 60.) Enclosed in it there occur magnetite crystals, sometimes also titanite and biotite. Between the scapolites there are small patches of a granular mass of feldspar, magnetite, titanite, biotite — probably a recrystallized porphyry groundmass — and a great quantity of rather large plates of brown biotite, reaching a size of some tenths of a millimeter.

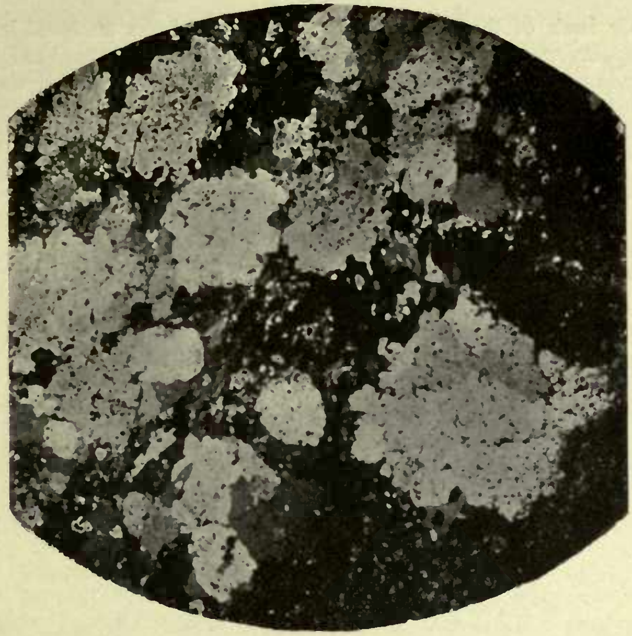

Fig. 60. Scapolite-biotite rock, in syenite-porphyry, Sakaravaara. Nic. +. Magn. 14 times. The large scalloped, white or gray areas are scapolite, between them is biotite and rests of porphyry groundmass. The structure is the one typical of the scapolite-biotite rocks of the Jukkasjärvi region.

The microscopic examination thus proves that the lenses of the scapolite-biotite rock only are altered parts of the syenite-porphyries.

The dense rock immediately north of the narrow band of quartz-porphyry consists of feldspar, quartz and biotite in almost equal quantities and of magnetite and small quantities of calcite. The feldspar is partly obviously plagioclase, other grains may perhaps be microcline. The grains generally reach a size of about 0,1 mm in diameter. The quartz forms irregularly polygonal grains. The biotite is olive brown and uniaxial; the magnetite forms single crystals or aggregates of crystals, the calcite occurs in irregular grains. All these minerals reach about the same size as the feldspars. The structure resembles »Pflasterstruktur», but the biotite plates are almost parallel to one another and the grains of the light minerals are somewhat elongated in the same direction.

A slide of the stratified rock of the more southerly band shows similar phenomena. The chief constituents are quartz, plagioclase, microcline, tourmaline and biotite, besides there occur some titanite, magnetite and orthite and in some streaks much scapolite and calcite. The tourmaline occurs in prisms reaching a length of about 0,1 mm, the pleochroism is O = bluish brownish green, E = pinkish; absorption O > E. The various streaks differ from one another by a somewhat dissimilar composition or size of grain. Some are quite short, resembling much elongated lenses, the width sometimes being only some tenths of a millimeter.

Chemical characters.

The only rock of these various types that has been analyzed is the gray one from the upper part of the southeastern wall of the Sakara Valley, the microscopic characters of which are described on p. 196. The analysis is made by R. Mauzelius, and gives the following result:

	XVIII	XVIII a
SiO_2	51.69	856
Al_2O_3	14.62	143
Fe_2O_3	9.24	58
FeO	5.14	71
MnO	0.08	1
MgO	3.74	93
CaO	4.49	80
BaO	trace	
Na_2O	6.77	109
K_2O	1.08	12
H_2O +	0.43	24
TiO_2	1.80	23
P_2O_5	0.46	3
CO_2	0.38	9
S	0.02	
	99.94	
H_2O −	0.08	

No. XVIII a. The molecular proportions of No. XVIII, multipl. by 1000.

The analysis is rather similar to No. I, of the Kiirunavaara syenite, but differs from it by having only half as high a percentage of K_2O and a twice as high of MgO. No more than No. I it resembles any analysis belonging to Osann's combination. The calculation show that the soda must partly appear as the jadeite molecule, which is a similarity to the »soda-greenstones» of the region.

Quartz-porphyries.

Macroscopic characters.

Northwest of the valley there is a quartz-porphyry area, elongated almost in the direction of the latter and about 40 meters in length and

half as wide. The rock contains small phenocrysts of feldspar and quartz in a dense pink-coloured groundmass.

The porphyry of the more southerly band is red or reddish gray in colour and contains small feldspar phenocrysts. It is rich in muscovite in rather large plates. Flow-structure is often seen.

The porphyry of the plateau always contains numerous rectangular phenocrysts of feldspar, reaching a length of a few mm, and rather small phenocrysts of quartz. The groundmass is almost dense, grayish red in colour, often with small spots rich in finely distributed magnetite. Muscovite is often seen, generally concentrated in aggregates. Strings of purple fluorite also occur. Flow-structure is rather common. The rock shows two jointing systems, one is vertical, with an almost southwesterly-northeasterly direction, the other one is horizontal. When there also appear transverse cracks, parallelopiped-shaped blocks are formed. Veins of quartz and hematite are seen here and there.

Microscopic characters

The rock in the most northerly area contains phenocrysts of microcline with some albite in microperthitic intergrowth, and phenocrysts of quartz reaching a size of up to 1 mm, with a rather irregular shape but showing no corrosion phenomena. Some of these quartzes are divided into fields with a different optical orientation, others show only a slightly undulatory extinction. The groundmass consists chiefly of quartz and feldspar, albite as well as microcline. The size of the mineral grains is about 0,1 mm, and the quartz occurs in rounded individuals. The absence of granophyric intergrowth seems to indicate the possibility that a recrystallization has taken place. Parallel streaks and elongated lenses with a coarser structure occur, the feldspar being predominant in them. Small quantities of magnetite, muscovite and calcite are seen in the groundmass.

In the more southerly band no quartz phenocrysts occur. Those of feldspar consist chiefly of albite with only small quantities of microcline. The groundmass has the same structure and coarseness as the above described one. Microcline is the predominant feldspar, magnetite is very abundant in small grains; some biotite, muscovite, calcite and tourmaline are also seen, the last one having the same pleochroism as in the neighbouring syenite-porphyries. Streaks of the same kind as in the above described rock occur, occasionally they reach several cm in length but only 1 mm in width. They consist of quartz, microcline and some albite in individuals reaching a few tenths of a millimeter in diameter, and often of muscovite in plates reaching a size of more than 1 mm, poikilitically larded with quartz. Calcite, magnetite and tourmaline are also seen.

The porphyry of the plateau has phenocrysts of microcline and albite (in about equal proportions) in a graceful microperthitic intergrowth, and phenocrysts of quartz which generally reach a diameter of 0,3 to 1 mm and sometimes have a distinct pseudo-bipyramidal habit. They are often rounded and show »corrosion bays». The extinction is often slightly undulatory but no crushing phenomena

occur. The groundmass is very like the one of the quartz-porphyry at the northern side of the valley. Magnetite is rather abundant in spots, zircon, calcite, muscovite and tourmaline are present in small quantities. Fluorite occurs in the coarser parts of the groundmass together with rather much calcite and muscovite.

Chemical characters.

An analysis of the quartz-porphyry of the plateau is made by R. MAUZELIUS and shows the following:

	XIX	XIX a	XIX b
SiO_2	75.62	1252	82.06
Al_2O_3	11.75	115	7.54
Fe_2O_3	1.95	12	—
FeO	0.83	12	2.36
MnO	0.04	—	—
MgO	0.17	4	0.28
CaO	0.39	7	0.46
Na_2O	3.63	58	3.83
K_2O	4.91	52	3.41
TiO_2	0.10	1	0.08
P_2O_5	0.01		
H_2O + . . .	0.20	11	
CO_2	0.22	5	
S	0.03		
	99.85		
H_2O — . . .	0.05		

No XIX a, the molecular proportions of No. XIX, multipl. by 1000; No XIX b, the same, calculated on a sum of 100, free from H_2O and CO_2, all Fe as FeO.

American system.

No. XIX.		*Norm.*		
Quartz	SiO_2	34.19	Q 34.19	Sal 96.20
Orthoclase . . .	$K_2O . Al_2O_3 . 6\ SiO_2$	29.07	F 61.01	
Albite	$Na_2O . Al_2O_3 . 6\ SiO_2$	30.55		
Anorthite . . .	$CaO . Al_2O_3 . 2\ SiO_2$	1.39		
Diopside . . .	$CaO . SiO_2$ 0.23; $MgO . SiO_2$ 0.20	0.43	P 0.63	Fem 3.49
Hypersthene . .	$MgO . SiO_2$	0.20		
Magnetite . . .	$FeO . Fe_2O_3$	2.55	M 2.86	
Hematite . . .	Fe_2O_3	0.16		
Ilmenite	$FeO . TiO_2$	0.15		

Sum 99.64 + H_2O etc. = 100.15

Class 1 Persalane, Subclass 1 Persalone, Order 4 Britannare, Rang 1 Liparase, Subrang 3 *Liparose.*

Osann's system.

s	A	C	F	a	c	f	n	k
82.14	7.24	0.30	2.70	14.5	0.5	5	5.3	1.76

Those among OSANN's types most similar to this one are the liparite types Comende with

s	a	c	f
82.5	15.5	0.5	4

and Cerro de las Navajos with

s	a	c	f
81.5	14.5	1	4.5

Inclusions of foreign rock.

In a few places there occur large inclusions of a foreign rock, the largest one is lenticular, reaching a length of more than 30 meters and a width of about 10 meters. The rock is massive, fine-grained, and has a dark gray colour on account of the high content of biotite.

The rock consist of plagioclase in individuals reaching a size of about 1 mm, nearly the half of them often being replaced by scapolite in sinuous grains and big plates of biotite; ilmenite is present in abundance, titanite occurs around it or on its cleavage cracks. Pyrite, quartz, apatite, calcite and fluorite also occur.

Metamorphism of the Sakaravaara rocks.

The very little damaged quartz phenocrysts show that the rocks have not been subject to any strong pressure. The coarser streaks which appear very distinctly in the groundmass of the quartz-porphyries are therefore no crushing zones. As regards their origin they seem to be equal to the nodules of the syenite-porphyries of the western district; some features in their mineralogical composition also seem to indicate this.

The groundmass of the quartz-porphyries is remarkable by the circumstance that the quartz has crystallized almost at the same time as the feldspar. It is possible that this structure is a primary one. From the same reason as is given above there seems to have been no recrystallization caused by pressure.

The tourmaline is probably a primary constituent of the quartz-porphyries, which also contain muscovite and fluorite. Whether it is primary also in the syenitic rocks is more doubtful. Among these rocks the development of scapolite and biotite is a form of metamorphism which seems to have befallen several different phases. It is remarkable, however, that this phenomenon is so very local. The same seems to be the case in other parts of the region as is shown especially by SUNDIUS' researches. He has also stated the vast distribution of scapolite in the regions south of Kiirunavaara, but he has as yet given no positive information of the cause of this vast metamorphism.

The fine-grained phase with »Pflasterstruktur» is evidently recrystallized. As it occurs exclusively in the neighbourhood of great masses of quartz-porphyry, it is probable, that we have to do with a contact metamorphism through the latter.

Exposures between Sakaravaara and Tuolluvaara.

Rocks east of lake Tuollujärvi. East of this lake there occur some outcrops of a red porphyry without visible quartz. The rock is often rich in magnetite, which occurs in narrow streaks and in larger spots, the centre of which is often filled with calcite. Veins of quartz occur, containing some red feldspar.

The feldspar phenocrysts, which reach a length of a few mm, are partly only albite, polysynthetically twinned with some cross-bars according to the pericline law, partly albite with microcline in a coarse microperthitic intergrowth. In one case the albite surrounds the microcline as a frame. The groundmass consists of albite and microcline in grains reaching a size of about 0,1 mm, and a considerable quantity of quartz, the latter being not as abundant, however, as in the quartz-porphyries of Sakaravaara. Magnetite occurs rather sparingly, squeezed in between the light minerals. About half the groundmass consists of rather coarse streaks parallel to one another and similar to those of the Sakaravaara quartz-porphyries. The width is seldom more than 1 mm. The chief constituents are quartz, microcline, magnetite and apatite; albite and biotite occur in somewhat smaller quantities, calcite, muscovite, tourmaline and zircon are more sparingly present. The magnetite occurs in lumps, the shape of which is determined by the light minerals, the apatite has the shape of irregular grains reaching a length of up to 1 mm. These streaks are evidently the macroscopically visible streaks of magnetite.

The Tuollujärvi ore field. In the marsh southeast of lake Tuollujärvi, a little to the east of the Tuolluvaara ore field, I. OLSSON SPETT in 1898 discovered an area of magnetite inclination, which has been given the name of the Tuollujärvi ore field. It has later on been examined by means of some diamond drill holes. The cores consist chiefly of a grayish red porphyry, often with irregular nodules of magnetite reaching a diameter of some mm. Magnetite ore occurs as small veins in the porphyry. The phenomena are evidently in many respects analogous to those at Tuolluvaara.

A slide of the nodular porphyry shows the following. The feldspar phenocrysts reach a length of some mm and show »striped» lamination. They are

badly idiomorphic. The groundmass consists chiefly of »striped» plagioclase in narrow rectangular sections reaching a length of 0,1 to 0,4 mm and with fringed borders. Small grains of plagioclase are sometimes enclosed. Besides there occur magnetite, apatite in a considerable quantity, biotite, calcite and some grains of zircon. The magnetite is abundant and makes up about 10 per cent of the groundmass apart from the nodules. With regard to the size there are all transitions from grains hardly reaching a diameter of 0,01 mm to the nodules. As a rule there occur no crystal forms, and the grains are squeezed in between the feldspars. The nodules are surrounded by a narrow zone free from magnetite. The feldspars close by the magnetite nodules are sometimes larger than is usual in the groundmass. At the border neither the feldspar nor the magnetite is idiomorphic. Single feldspars are sometimes enclosed in the magnetite lumps.

The Tuolluvaara ore field.

Introductory remarks.

The small hill of Tuolluvaara is situated about 4 kilometers east of Kiruna and rises 45 meters above the surrounding woods and marshes. The ore deposit there was discovered in 1897 by HJ. LUNDBOHM with the help of the inclination compass. The hill war then almost entirely covered with moraine in part up to six meters deep. At the mining operations, magnetic measurements have been used with great advantage to determine the situation of the ores. The profit of this method is considerable as the moraine is very hard and full of large boulders, which renders its removal very expensive.

As to the mode of occurrence of the ore, Tuolluvaara has an intermediate position between Kiirunavaara-Luossavaara and the breccia ore of Mertainen; it is similar to some ores of Gellivare Malmberg. The ore forms dikes and bosses in a reddish quartz-porphyry, which is almost everywhere interwoven with innumerable dikes of ore, from strings of microscopic dimensions to dikes having the size of workable ore bodies. This ore breccia is rather similar to the one of northern Kiirunavaara. Syenite-porphyry occurs in very subordinate quantities.

Quartz-porphyry.

Macroscopic character.

On account of the thick morainic covering it has been possible to examine the country rock only in the neigbourhood of the larger ores.

The rock has a pink or reddish gray, less often quite gray, colour. Relatively few phenocrysts of feldspar, reaching a size of 2 to 4 mm, lie

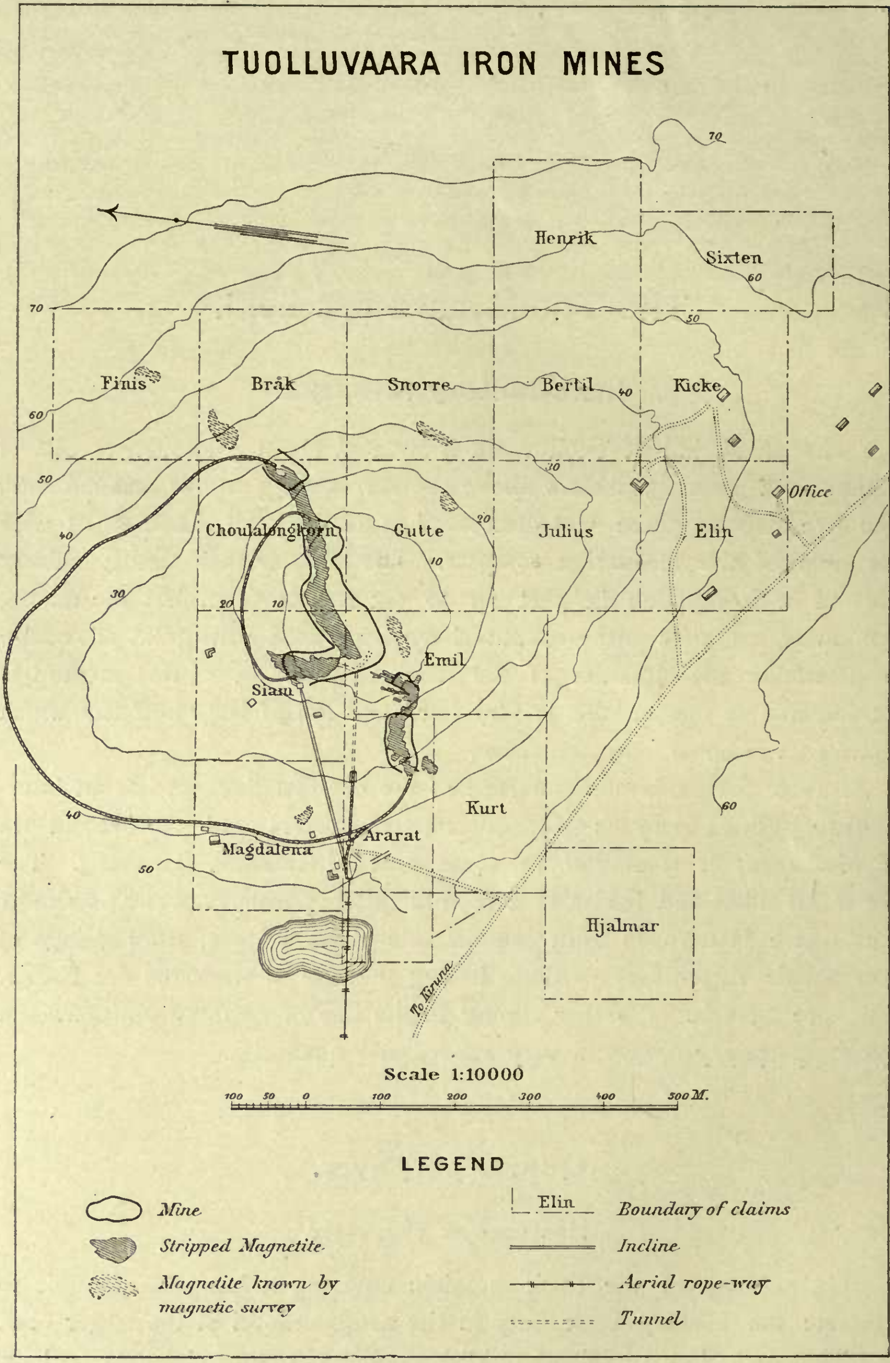
TUOLLUVAARA IRON MINES
Henrik
Sixten
Finis
Bråk
Snorre
Bertil
Kicke
Office
Choulalongkorn
Gutte
Julius
Elin
Emil
Siam
Kurt
Ararat
Magdalena
Hjalmar
To Kiruna
Scale 1:10000
100 50 0 100 200 300 400 500 M.
LEGEND
Mine
Stripped Magnetite
Magnetite known by magnetic survey
Elin
Boundary of claims
Incline
Aerial rope-way
Tunnel

Fig. 61.

in a very fine-grained or dense groundmass. It resembles the rocks of the outcrops east of Tuollujärvi rather much, as well as the quartz-porphyry of the Sakaravaara plateau, but lacks the quartz phenocrysts of the latter. There sometimes occurs a very beautiful parallel structure, generally marked by narrow streaks of magnetite, much more seldom also of hornblende. These magnetite streaks are generally not 1 mm wide, but may have a length of several dm; the porphyry on both sides is reddish within a zone reaching a width of a few mm, otherwise it is reddish gray. The streaks generally lie at a distance of some mm from one another, they are quite straight and parallel to one another. There are often seen many tens of streaks quite parallel to one another. Anastomosing is, however, sometimes seen. Nodule-like aggregates of magnetite also sometimes occur. This beautiful porphyry type seems to be best developed in the northwestern part of the ore field.

Microscopic characters.

The feldspar phenocrysts generally show broadly rectangular sections with a neither very good, nor very bad idiomorphism. They consist as a rule of albite and microcline in microperthitic intergrowth and in about the same proportions. In sections in the zone of symmetry both components alternate in irregular fields, but in sections nearly parallel to (010) they alternate in narrow stripes. The albite is sometimes not lamellated. Sometimes the phenocrysts consist almost entirely of albite.

The groundmass consists chiefly of feldspar and quartz, the former often being rather predominant. Microcline often seems to be more common than albite. The size of grain as well as the structure is similar to that of the quartz-bearing rocks of Sakaravaara. Magnetite constitutes at least some per cent, it forms grains reaching a size of 0,1 mm at the utmost and is now enclosed in the light minerals, now lying between them. Hornblende, similar to that of the syenite-porphyries of Sakaravaara, occurs in the shape of short, irregular prisms, which sometimes may reach a length of up to 1 mm. Brown biotite often occurs together with the hornblende, especially on its cleavage cracks. These dark silicates have mostly been observed in the brecciated phases of the porphyry and it is possible that they are partly of secondary origin.

A slide of porphyry with magnetite streaks shows the following. The streaks are generally intimately connected with the normal groundmass, more seldom sharply defined. They do not run through the feldspar phenocrysts, but continue on the other side of them. Many of them are only extremely elongated lenses. The mineral constituents are magnetite, which is most common, quartz and microcline, which vary in quantity to the total absence of one or two components, and very subordinately tourmaline, titanite, apatite, zircon, orthite. The quartz and the microcline form irregular grains reaching a diameter of 0,2 to 0,5 mm the magnetite lies between these minerals and only seldom shows crystal forms. The tourmaline is pleocroic with O = bluish green; E = pinkish; it occurs in thick prisms with a length of 0,1 to 0,2 mm. It is also sparingly

present in the groundmass outside the streaks. These streaks are evidently, as those of the other rocks in this district, of a primary nature and equal to the nodules of the syenitic rocks of the western district.

Chemical characters.

A specimen of the grayish red, typical quartz-porphyry has been analyzed by G. NYBLOM.

	XX	XX a
SiO_2	70.08	1160
Al_2O_3	13.83	135
Fe_2O_3	2.97	19
FeO	1.04	14
MnO	0.02	—
MgO	1.10	27
CaO	0.83	15
Na_2O	5.33	86
K_2O	3.84	41
TiO_2	0.40	5
P_2O_5	0.02	—
H_2O +	0.47	26
S	0.04	1
	99.97	
H_2O —	0.16	

No XX a gives the molecular proportions of analysis No. XX, multipl. by 1000.

The rock is evidently closely similar to the quartz-porphyry of the Kiirunavara-Luossavaara district. The relatively high content of MgO is probably due to microscopic veins of hornblende.

Syenite-porphyry.

This rock occurs as a short schliere-like body, hardly 1 meter wide, near the ore of Magdalena, and around the westernmost part of the ore of Ararat. It is brownish gray, fine-grained and rich in biotite and magnetite. The contacts with the quartz-porphyry are seen in the former case only, they are quite sharp.

A slide of the rock of this type exposed in the claim of Magdalena shows the following features. Some finely laminated plagioclase phenocrysts, the largest one 1 mm in length, are lying in a groundmass chiefly consisting of trachytoidally arranged individuals of the same mineral, reaching a length of 0,1 to 0,2 mm and with sinuous outlines. The striation is often extremely fine, the refraction

always lower than that of quartz, which seems to indicate oligoclase-albite. Quartz occurs but very sparingly, biotite is more abundant, it is nearly totally altered to chlorite, and occurs in plates reaching a length of 0,1 mm and elongated in the same direction as the feldspars. Magnetite constitutes at least 5 per cent, it is squeezed in between the feldspars and shows no crystal forms. Apatite is rather common and occurs in the shape of elongated grains reaching a length of 0,25 mm at the utmost. Titanite occurs very sparingly. Some nodule-like aggregates of quartz and plagioclase are seen.

The rock surrounding the western end of the ore of Ararat resembles the above described one rather much. The feldspar phenocrysts are more numerous and broadly laminated, the refraction is a trifle lower than that of the Canada balsam. Very small patches of potash-feldspar are associated with the plagioclase in microperthitic intergrowths. The feldspars of the groundmass are not as elongated as in the above described rock, and quartz is present only in small quantities; the magnetite on the contrary constitutes about 10 per cent, and the apatite at least 5. In other respects this rock is quite similar to the precedent one

Pegmatitic dikes and veins.

Such rocks occur almost exclusively in the neighbourhood of the western end af the ore of Ararat, especially in the syenite-porphyry areas inserted in the ore. Great quantities of them have been quarried away during the mining operations, and have landed on the dumps where the writer has collected the greatest parts of the material used by him.

In their most inconsiderable form these pegmatites are composed of scarcely 1 cm wide strings, consisting of red feldspar in individuals reaching a length of some mm and of bluish magnetite; they are always intimately associated with the normal rock. In larger bodies of the same kind the feldspars reach a length of 3 to 4 cm. The microscopic examination shows them to be microcline.

One little vein is fine-grained and consists of red feldspar, quartz, magnetite and biotite. Small crystals of quartz are seen in druses. The microscopic examination shows that the feldspar is mostly albite in elongated individuals with smoothly rounded corners. These albite crystals are often surrounded by an optically homogeneous area of a mineral with lower index of refraction and rich in red pigment. This mineral, which is doubtless potash-feldspar, is sometimes also intergrown with the albite in a perthitic manner; it shows crystal outlines towards the quartz, which has no tendency to idiomorphism. Apatite is rather abundant and titanite occurs in partly idiomorphic crystals. The contact towards the normal rock is distinct but not sharply defined.

There also occur coarse veins of feldspar and quartz in varying proportions, and veins of quartz with large plates of biotite. Most veins are only a few cm wide.

Other veins contain only little feldspar (generally accumulated along the borders) and quartz, but consist chiefly of pale green, coarsely crystalline apatite, and of magnetite in lumps reaching a diameter of several

Fig. 62. Pegmatite vein, Tuolluvaara. ²/₃ of nat. size. Crosses = syenite-porphyry; white = quartz; dotted = feldspar; black = magnetite; striated = apatite.

cm. The largest vein of this kind is seen in fig. 62, it is, however, not especially rich in apatite. The veins send out apophyses and often enclose fragments of porphyry. The width varies suddenly, as is common with pegmatites.

None of these pegmatites are seen in contact with the ore or with magnetite dikes.

Ore breccia.

Macroscopic characters.

The dikes interweaving the porphyry consist chiefly of magnetite, often with hornblende and apatite, and even the small ones are generally quite similar to the workable ores as regards composition and structure. The contacts with the porphyry are nearly always sharply defined. The dikes are generally almost straight, but often branch out and anastomose. The net of dikes is sometimes so thin that one can see areas of porphyry, measuring almost 1 square meter, between the magnetite bands, but in other cases the porphyry may sometimes be splitted into scarcely 1 cm

Fig. 63. Orebreccia, claim of Emil, Tuolluvaara.

long fragments separated from one another by ore. Even when the latter is predominant, the fragments are generally angular.

In the ore dikes, especially when the porphyry is highly brecciated, there are often seen lumps of quartz or calcite. These lumps reach a diameter of some cm and often contain large plates of biotite. In the quartz there are often seen chalcopyrite and titanite, in the calcite often magnetite. In one case calcite has been found to occupy the middle of a small magnetite dike. Hornblende and crystals of apatite, reaching a length of some cm, often occur.

Fig. 63 shows a common breccia type: rather spare ore dikes, branching out or anastomosing; fig. 64 shows several dikes uniting to form an ore mass with angular porphyry fragments; fig. 65 is a typical breccia with small fragments.

Microscopic characters.

Beside the constituents of the ore dikes already mentioned, there also occur biotite and some quartz, the latter being perhaps in part detached from the porphyry. Even small dikes are generally sharply defined, but the very smallest, the capillary strings, often dissolve into a row of isolated magnetite crystals, farther off forming a coherent line again. Patches and streaks rich in magnetite also occur in the groundmass. The cleavage cracks of the feldspar phenocrysts are very often filled with magnetite with crystal forms, in the same way as has already been described with regard to the wall rocks of Kiirunavaara. These magnetite crystals have evidently originated after the crystallization of the feldspar phenocrysts. The magnetite's being rather well idiomorphic does accordingly not always denote that it is older than the enclosing minerals; it is therefore difficult

Fig. 64. Orebreccia, claim of Emil, Tuolluvaara.

to settle how much of this mineral in the porphyry fragments is of a primary nature. It seems to be most probable that the formation of all such strings has been contemporaneous with that of the ore dikes. Small equally distributed magnetite grains, that sometimes occur, seem, however, to be of a primary origin.

A peculiar and rather widely distributed form of breccia requires a special description. Macroscopically it has the appearance of an usual red porphyry interwoven with hornblende strings, close by which the rock generally has a greenish gray colour. When the veinlets are very numerous the whole rock has this colour. One might therefore think that it is caused by an impregnation with hornblende and that the red areas, though hornblende strings sometimes pass through them, are unaltered parts of the same rock. The microscopic examination shows that the grayish rock is rich in magnetite and in hornblende in small compact individuals, but is almost free from quartz. The red part, on the contrary, contains quartz in the quantity usual with the quartz-porphyry, but is almost free from dark minerals. The border is rather distinct, but appears, as regards the quartz content, only at a close examination.

The Ore.

Physical properties.

The ore often shows two systems of jointing, one following the dip of the ore body, the other making an angle of about 84° with the latter.

It is often strongly naturally magnetic (loadstone).

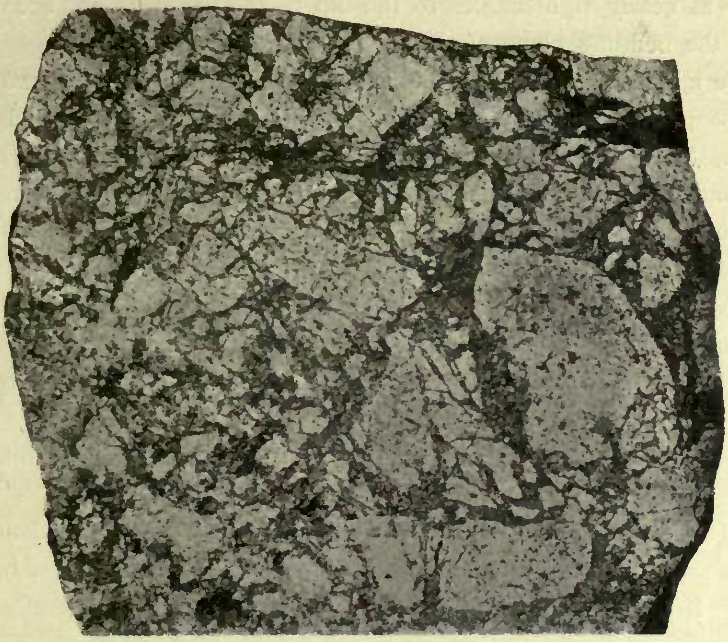

Fig. 65. Orebreccia, Tuolluvaara. Nat. size.

Macroscopic characters.

The Tuolluvaara ore consists almost exclusively of magnetite, but also contains a small quantity of hematite. The most important barren mineral is here, as in other magnetite ores of the region, the apatite, but the quantity of the latter is much lower than in the greater part of the Kiirunavaara ore, which also appears from the fact that such a great proportion of the ore passes below the Bessemer limit. Other impurities are amphiboles and mica.

The magnetite is generally finely crystalline, blackish blue, on a weathered surface often quite blue, it is not as hard as the dense ores of

Kiirunavaara and Luossavaara. In one place there has been observed a small streak — only some cm wide — of dense black magnetite, in the common, finely crystalline variety. The hematite sometimes occurs in abundance in crystal lumps often reaching a size of several cm. These lumps are often arranged in parallel rows which coincide with a system of joints. In the southernmost part of the claim of Chuolalongkorn this phenomenon is very distinct, the joint system in question is the one running at nearly right angles to the dip of the ore mass, and accordingly also to the bedding plane of the »stratified ore». (See below!)

The apatite is generally white or grayish green in colour and occurs in small grains, which often gather in thin streaks quite parallel to one another. Such »stratified ore» is rather widely distributed near the hanging wall contact in the southern part of the claim of Chuolalongkorn and in the claim of Ararat. In strike and dip it follows the ore body as a whole. The stratification is less regular than in the similar ore type of Kiirunavaara, especially the thick streaks are often quite short. Here and there the apatite occurs in large crystals reaching a length of some cm, it then shows a distinct cleavage parallel to the pinacoid and is rather well idiomorphic towards the magnetite.

Of amphiboles there are hornblende and asbestos present. The green hornblende resembles that of the Kiirunavaara ore. It is equally distributed or concentrated in streaks, but is never very abundant. The asbestos is white and often occurs in streaks parallel to the bands of apatite. It is sometimes associated with hornblende but generally occurs alone.

The black biotite is rather rare. The individuals sometimes reach a diameter of some cm.

In druses there occur crystals of calcite, quartz (often as amethyst), hornblende and magnetite.

Microscopic characters.

A slide of finely »stratified ore», cut at right angles to the bedding plane, shows the following. The apatite layers consist of prisms reaching a length of 1 to 1,5 mm and a thickness of 0,3 to 0,7 mm, lying in a single row. Small individuals in inconsiderable quantities are seen here and there. Single, very small magnetite crystals are enclosed in the apatite. The ore layers consist of magnetite with much apatite in equally distributed grains reaching a size of 0,10 to 0,15 mm in diameter and elongated in the direction of banding. The outlines between these grains and the magnetite are jagged and seem to indicate that

the apatite has crystallized only shortly before the magnetite. A slide of an apatite layer, cut parallel to the bedding plane, shows a quite massive aggregate of prisms of the above stated size, between which small lumps of magnetite are squeezed in.

Small plates of red hematite often occur in the apatite.

The highly fibrous asbestos often encloses pieces of almost compact amphibole, the latter being quite colourless too. There also occurs in the ore a species of amphibole different to the other ones of the region. It is compact with relatively few but very marked cleavage cracks and is colourless with only a pale tinge of red in some sections. The optical orientation is that of common

Fig. 66. »Stratified ore», Tuolluvaara, at right angles to the bedding plane. Ord. light. Magn. 14 times. White is apatite, black magnetite.

hornblende. It occurs in thick prisms having a length of some tenths of a millimeter; they are idiomorphic towards the apatite and are often enclosed in the large crystals of this mineral. Zircon occurs in the same manner as in the Kiirunavaara ore.

Description of the ore bodies.

Claim of *Magdalena*. The exposed ore area is wedge-shaped, with a maximum width of about 6 meters. No mining operations have been performed in it as yet. Near the borders towards the porphyry, the ore at the sides, as well as at its northern end (the southern one is covered

with moraine), contains numerous porphyry fragments, the latter being not angular, but sinuous, generally elongated paralel to the contact. Such inclusions are sometimes also seen in the middle of the ore. They seem to follow the dip of the ore body, which appears in the jointing. They are often almost white in colour.

A slide shows them to consist of porphyry groundmass with the common structure but extremely rich in quartz. Of feldspar there is only albite present. The ore between these lumps is also rich in quartz which has partly crystallized before the magnetite. The ore contains short layers of apatite, striking and dipping in the same way as the rock fragment. The wall rock is a striped porphyry, the magnetite streaks striking and dipping conforming to the above mentioned bodies contained in the ore.

Fig. 67. Fragment of »stratified ore» in massive, pure ore. Claim of Chuolalongkorn, Tuolluvaara. The figures on theb and mark centimeters.

Claim of *Siam*. The ore has a maximum width of about 25 meters and on a whole dips steeply to the east, with some irregularities. The ore is mostly low in phosphorus, but the »stratified» type occurs along the foot wall.

Immediately southwest and northeast of the ore the porphyry is highly brecciated, southeast of it it is only cut by a few ore dikes, and at the northwestern contact no dikes at all are seen. The writer has not had an opportunity of seeing the district between this ore body and the Emil-Chuolalongkorn ore dike before it was broken through by mining operations. Large slicken-sides appearing in the walls of the open cut indicate here great disturbances after the complete solidification of the porphyry.

Claims of *Emil* and *Chuolalongkorn*. Within these claims the greatest ore body of the field is to be found, extending chiefly in the latter. It has a length of at least 280 meters, the width is within the southwesternmost part about 25 meters, otherwise generally 15 to 20 meters. Near its northeastern end it encloses a »horse» of porphyry. The dip is, according to what has hitherto been ascertained by mining, to the southeast. For some 170 meters from the southwestern end the ore belongs to the A[1] and C qualities in about the same proportions, the latter follows the hanging wall and is partly well »stratified». On the natural surface, polished by the great ice sheet, there were distinctly seen large inclusions of stratified ore in a massive, more pure type. Such a one is shown in fig. 67. The contact resembles that of an igneous rock with a stratified inclusion of a sedimentary rock.[2] In the northeastern parts of this ore the A quality is predominant, with only small C areas.

Claims of *Bråk* and of *Finis*. (North of Chuolalongkorn). Only small ore areas are exposed. At Bråk the ore is very rich in apatite, occurring in flattened lenses.

Claim of *Ararat*. In the porphyry surrounding the isolated rounded ore body there are only a few ore dikes. The same is the case with the wall rock of the western end of the larger ore mass, where, however, small pegmatites are common. (See above p. 209). More to the east there occurs a beautiful ore breccia, closely connected with the ore body; a similar breccia also occupies the area between this ore and the southwestern end of the above described large ore dike. Especially near the hanging wall the ore is rich in apatite and rudely »stratified». The dip is about 45° to the south, as is also the case with that of the apatite layers. The jointing is very distinct.

Claim of *Snorre*. (East of Emil) The ore is exposed to a width of about 5 meters. The wall is the common quartz-porphyry, without magnetite dikes.

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[1] In Tuolluvaara maximum 0,015 per cent P.
[2] Another reproduction of such an inclusion is found in STUTZER [62].

Eastern Tuolluvaara.

Some hundred meters east-southeast of the ore field there is a group of outcrops measuring about 1 500 square meters. In the northernmost part a well has been sunk. The rock is there fine-grained, often porphyritic, and reddish, with dark minerals, chiefly biotite, distributed in spots. It is sometimes rich in magnetite and even contains small ore segregations reaching some cm in diameter; the ore is crystalline and bluish, similar to that of the ore field. At one side the rock changes into phases nearly free from dark minerals, at the other one into phases having a high content of biotite and magnetite. East of it there occurs a rock very rich in hornblende and with grayish or greenish feldspar, this type fills the greatest part of the exposed area. All these rocks are cut by dikes of a fine-grained, pink rock. The dikes reach a width of up to more than 1 meter and are straight and sharply defined. At the well there also occur small drusy pegmatite dikes of red feldspar, quartz and apatite.

A slide of the rock at the well shows that its composition is very similar to that of the typical porphyry of the ore field. The feldspar phenocrysts, which reach a size of up to 7 mm, are mostly microperthitic and composed of albite and a very small quantity of microcline. The intergrowth resembles that of the phenocrysts of the porphyry of the ore field. There also occur phenocrysts which are homogeneous and show very fine striation and in places cross-twinning like the presumed soda-microcline of the Kiirunavaara syenite. The groundmass is made up chiefly of feldspar and quartz, with some biotite, magnetite, titanite, apatite, zircon and pyrite. The feldspar is partly microperthite, partly free microcline and albite; the size varies between 0,1 and 0,6 mm. The magnetite occurs in idiomorphic crystals, 0,10 to 0,15 mm in diameter. The quartz forms isometric grains, otherwise the structure is granitic.

The rock rich in hornblende shows quite different characters. The feldspar is a striated plagioclase, the refraction of which is considerable higher than that of the Canada balsam, it is to a rather great extent altered to scaly muscovite or sometimes to scapolite. Most individuals reach a length of one or a few mm, smaller grains are squeezed in between them. The hornblende shows strong

pleochroism: $\mathfrak{a}$ = pale yellow; $\mathfrak{b}$ = grass green; $\mathfrak{c}$ = bluish green; absorption $\mathfrak{b} = \mathfrak{c} > \mathfrak{a}$. It forms very irregular patches and is probably of secondary origin. Biotite and titanite are also present, but magnetite is scarcely seen.

The dike rock consists principally of feldspar and almost as much quartz. The former is generally microcline, but free plagioclase also occurs. The size of grain is 0,1 to 0,8 mm. The quartz forms isometric grains 0,1 to 0,2 mm in diameter, generally several together. The structure — as well as the composition — is aplitic and probably primary. Titanite, apatite, biotite, pyrite and zircon are present in small quantities.

Exposures northwest of Tuollujärvi.

Four porphyry outcrops there consist of schlieric and inhomogeneous rocks, varying from a pink-coloured type rather similar to the quartz-porphyry of Tuolluvaara, to dark femic phases.

The microscopic examination shows, that the feldspar phenocrysts, reaching a length of a few mm, are »striped» albite. They show broadly rectangular sections. In the most siliceous phases there also occur quartz phenocrysts reaching a diameter of some tenths of a millimeter; they are by a poikilitic zone connected with the groundmass, that consists of a mixture of quartz and feldspar in grains reaching a size of 0,1 mm or somewhat less. The feldspar is generally laminated. The quartz occasionally occurs in rather big individuals, poikilitically larded with feldspars, but in the more basic phases, where it is very rare, it occurs only in isometric grains. Of dark minerals pyroxene and hornblende are the most important. The pyroxene is a light yellowish green augite with a weak pleochroism and an extinction angle of about 45°. It forms skeletons reaching a size of more than 1 mm. The hornblende is strongly coloured, bluish green, and occurs in elongated grains, some tenths of a millimeter in length, with rather good idiomorphism in the prism zone. It appears to be more common than the pyroxene and is sometimes associated with the latter, but it is always compact and is probably not uralite. For the rest, there are seen single crystals of magnetite, grains of apatite and of reddish titanite. Calcite is sometimes present in abundance.

Close to the Kiruna road some hundred meters west of Tuolluvaara there is an outcrop of rocks macroscopically similar to those just described.

The microscopic examination of the most reddish phase, however, shows no quartz. The rock is even-granular, the feldspars reaching about 0,1 mm in diameter. They are partly acid plagioclase, partly rich in pigment and consequently probably potash-feldspar. Dark minerals occur in great quantities; the bluish green hornblende and the titanite are allotriomorphic, but the magnetite occurs in idiomorphic crystals. The structure is probably primary.

Exposures along the brook of Luossajoki.

Where the brook flows out from the lake Ala Lombolo there are outcrops of the Hauki quartzite-sandstone, with conglomerate beds. About 500 meters east of these there is a group of outcrops of amphibolite and porphyrite. The exposed area is scarcely 70 meters wide. 100 meters are then covered, and then there is porphyry, first a group of outcrops with a width of about 30 meters and after 145 meters another group. After that there are no outcrops near the brook until east of Tuolluvaara.

Porphyrite and amphibolite.

These rocks are rather strongly schistose, striking almost north and south and standing nearly vertically. They seem to have been subjected to pressure. They vary from fine-grained, dark amphibolite to porphyrite with numerous but irregular white feldspar phenocrysts, reaching a length of some mm. Nodule-like aggregates of epidote are often seen, as well as small streaks of quartz and chalcopyrite.

Under the microscope the badly idiomorphic phenocrysts of the porphyrite are seen to be broadly lamellated and to have a much higher refraction than the Canada balsam. They therefore seem to be akin to labradorite. Epidote and zoisite are products of alteration and are rather abundant. The groundmass consists chiefly of plagioclase in isometric grains reaching a size of about 0,1 mm in diameter, the refraction is scarcely lower than that of the phenocrysts. There also occur much hornblende in short stalks, some magnetite and a rather considerable quantity of the secondary products epidote and zoisite.

Together with the greenstones east of Luossavaara and Nokutusvaara, examined by ZENZÉN, and the exposure north of Sakaravaara, described on p. 195, these outcrops at Luossajoki form a possibly coherent band of basic, always at least somewhat metamorphic rocks. The composition seems to be about the same as that of the basic rocks of eastern Tuolluvaara.

Quartz-porphyry.

Macroscopic characters.

This rock is very similar to the quartz-porphyry of Tuolluvaara, but is still more akin to the hanging wall rock of Kiirunavaara-Luossavaara, from which it, however, as a rule can be rather easily distinguished. It is rather rich in pinkish feldspar phenocrysts reaching a length of more than 1 cm, they are generally not rounded nor do they have quite regularly rectangular sections. The groundmass is very fine-grained and is generally of a reddish colour. Small streaks of magnetite are often seen. A somewhat different type occurs quite locally, it is rather grayish on account of finely distributed biotite in the groundmass.

One outcrop shows very remarkable phenomena. In the middle it consists of long bands and elongated lenses of the usual porphyry, embedded in a fine-grained matrix, similar to the groundmass of the porphyry, but having no phenocrysts at all. The bands of porphyry run north and south; they may as a rule be characterized as extremely elongated lenses. One of them is 108 cm long, but only 8,5 cm wide. Some of them end in a long tail consisting of a row of phenocrysts. The matrix is massive, and very similar to the groundmass of the porphyry, only a little grayer. It is quantitatively somewhat subordinate to the porphyry lenses and sometimes shows distinct folds, as if it in a gluey, half liquid state had been squeezed in between them. At the eastern border of the outcrop a similar but more deeply reddish rock is most commonly seen, but to the west the normal porphyry is predominant, including single narrow streaks of the non-porphyritic rock.

Microscopic characters.

The phenocrysts of the normal porphyry appear under the microscope to be composed as those of the syenitic dike-porphyries of Kiirunavaara and the quartz-porphyry of the western district, consisting of »striped» albite with some potash-feldspar in microperthitic intergrowth. The idiomorphism is rather good. Rhombic shape is sometimes seen. The groundmass is fine-grained (the size of the grains being somewhat less than 0,1 mm), microgranitic, with a rather high content of quartz. Among the feldspars there are seen many plagioclase grains but also many grains with the characteristic cross-twinning of the microcline. The chief dark constituent is magnetite, occurring in small, angular grains. Greenish brown biotite and apatite occur more sparingly. The rock contains

streaks similar to those of the Sakaravaara and Tuolluvaara quartz-porphyries, consisting of magnetite, apatite, quartz, microcline, albite, biotite and tourmaline.

A slide of the grayish variety shows phenocrysts of »striped» albite, sometimes with microcline in a coarse microperthitic intergrowth, sometimes sponge-like, poikilitically larded with small feldspar and quartz grains. Others are more broadly laminated and in the centre altered to epidote, which indicates a higher content of the anorthite molecule. The groundmass consists of microcline and quartz, both in isometric grains reaching about 0,1 mm in diameter, smaller quantities of plagioclase and biotite and sparingly magnetite, titanite and apatite.

The matrix in the especially noteworthy outcrop is rather similar to the just described groundmass. The feldspar (microcline and some albite) occurs in individuals reaching 0,10 to 0,25 mm in diameter, the quartz in somewhat smaller, often rounded, grains. There also occur magnetite, now with crystal faces, now younger than the light minerals; somewhat faded mica and isolated grains of zircon, apatite and titanite. Tourmaline occurs sparingly in small idiomorphic crystals. The rock is sometimes interwoven with very narrow strings of a very fine-grained quartz-feldspar mass, rich in red pigment.

It is rather difficult to determine the nature of the rock of this peculiar outcrop, but it is probably a volcanic flow-breccia.

Exposures at Rotsejoki.

Quartz-porphyry.

The wide and sharply defined glen is probably of fluvio-glacial origin, and the brook now flowing through it is very small. Along the sides of the glen and here and there at the bottom of it there are extensive exposures of a porphyry altogether resembling the type predominant at Luossajoki and also, as the latter, including small areas of a more grayish colour.

The feldspar phenocrysts are badly idiomorphic and consist of albite and microcline in very varying proportions in a now fine, now coarse microperthitic intergrowth.

A slide of the grayish variety has rather much scapolite in the phenocrysts, and besides tourmaline in allotriomorphic individuals reaching some tenths of a millimeter in diameter. Some phenocrysts are partly altered to muscovite. The groundmass consists chiefly of microcline in grains reaching a size of about 0,1 to 0,2 mm, a little plagioclase and quartz in somewhat smaller grains. Magnetite, apatite and titanite occur more sparingly, the titanite often surrounding the other two. Biotite is common in the gray variety, which even in the groundmass contains some scapolite. The present material does not make it possible to ascertain whether the last mentioned mineral is limited to this type and is not to be found in the common, red rock.

In one place a joint in the porphyry is surrounded by a mass of coarsely crystalline, green hornblende, some cm wide, enclosing some brown titanite crystals, one of which is about 6 cm long.

The porphyry encloses an area of scapolite-biotite rock, 40 meters in length and 10 meters in width, more rich in biotite than the similar bodies occurring at the Sakara Valley and also containing some green hornblende, but otherwise very like them. Under the microscope there are here and there seen small fine-grained areas chiefly consisting of plagioclase. On the border to the porphyry there occur masses nearly free from biotite, consisting of scapolite with isolated skeleton crystals

of yellowish green augite and short prisms of bluish green hornblende as well as small quantities of red titanite, apatite and magnetite.

Porphyrite.

About 1 kilometer east of the porphyry outcrops there are some very low outcrops of fine-grained, greenish gray rocks. They are somewhat porphyritic and consist of a basic plagioclase in isometric grains, single skeleton crystals of augite and short prisms of hornblende. Magnetite, biotite and titanite occur in small quantities. Scapolite is common and occurs in individuals having a size of about 1 mm, often gathered in aggregates causing the appearance of white spots in the rock.

The rocks of Rotsejoki are closely related to the rocks of Mount Vahåive, which have been examined by SUNDIUS. A red quartz-porphyry is dominant there, being in all principal respects similar to the above described one.

The Rakkurijoki ore field.

This ore field was discovered in 1898 by K. HANNU, with the aid of the inclination compass. It is situated about 5 kilometers south-south-east of Jägmästaren, Kiirunavaara, and 1,5 kilometers west of the Gellivare-Kiruna railway.

The whole area was covered, but the ore has been exposed in an excavation pit. It is fine-grained magnetite, containing numerous small plates of talc, which are often gathered in bands. The analysis of a typical hand specimen shows according to PETERSSON [53]:

Fe	42,31 %
P	0,25 »
TiO_2	0,21 »

This ore deposit has afterwards been examined by diamond drilling. (After this the deposit has not been worked as it is evidently of small value.) The cores have been studied by the writer, but the pieces were then not arranged in their original order and it was accordingly quite impossible to get a closer knowledge of the relation between the ore and the surrounding rocks. The greater part of the ore cores had probably also been taken away from the series.

Some cores are a mixture of talc and magnetite. The latter is idiomorphic. The talc occurs in plates reaching a size of about 0,1—0,3 mm. Besides there occur apatite as well as some serpentine and calcite, all these minerals being visible only under the microscope. A slide of more pure ore shows in the magnetite mass small, equally distributed talc plates, isolated short prisms of an almost colourless amphibole, and much pyrite.

The rock accompanying the ore is gray or reddish gray with small feldspar phenocrysts in a very fine-grained groundmass. The microscopic

examination shows it to be a porphyrite which resembles certain rocks occurring some kilometers further south. The feldspar phenocrysts, which reach a size of up to 1 cm, are plagioclases with albite lamination. The refraction is considerably higher than that of the Canada balsam, sometimes indicating labradorite. Besides there are some rather small, badly idiomorphic phenocrysts of a light greenish augite. The groundmass consists chiefly of a plagioclase (probably basic oligoclase, judging from its optical properties) in grains having a diameter of about 0,1 mm, rather small grains of an augite of the same kind as the phenocrysts, and of small quantities of hornblende, biotite, magnetite, apatite and titanite. Scapolite is often seen in the groundmass, sometimes also replacing the outer parts of the feldspar phenocrysts or filling fissures in the rock.

It is of course impossible to explain the relations of these rocks to those already described.

THEORETICAL STATEMENTS.

Chemical characters of the igneous rocks of the Kiruna region.

General characters. All important analyses have been calculated in the above according to the american system and that suggested by OSANN and have been compared to analyses of igneous rocks of similar chemical characters. The writer now intends to give a short survey of the features common to the different analyses, such as appear to be characteristic of the series of igneous rocks to which those of the Kiruna region belong, and also to treat the dissimilarities between the different kinds of rocks of the region. The material present is, however, not sufficient to give a satisfactory chemical classification, in spite of the great number of analyses and their great reliability. In order to make such a classification there is also required knowledge of the more basic phases of the series, and these are not present among the ore-bearing ones and are not very well-known as yet.

In the Kiruna rocks, the Al_2O_3 amount beyond that uniting with the alkalis to form orthoclase and albite is low, but there always exists such an excess, this being the reason why the acmite molecule never appears in the calculation. The anorthite percentage is as a rule most low in the most siliceous rocks, but it does not at all increase regularly as the SiO_2 percentage of the rock sinks. It is rather high in No. IV, which has $59{,}71$ SiO_2, and considerably lower in No. I, where the SiO_2 percentage is $53{,}31$. The same features are still more pronounced in No. XII, the albite-magnetite rock.[1] This strong alkaline character also appears at the fitting of the analyses into the chemical classification systems: in the american system they nearly all belong to the first, the

[1] This character also appears very distinctly in the »soda-greenstones» examined by ZENZÉN and SUNDIUS and lying below the Kurravaara conglomerate.

peralkalic rang, in OSANN's system we find them in the »Erste Vertikalreihe». But there are, however, no true »Alkaligesteine» containing dark alkali silicates (with the acmite molecule) present, nor any feldspathoid minerals. Therefore, our rocks cannot belong to the »Alkali-Reihe» of Rosenbusch.[1]

Among the alkalis, sodium is always predominant from the point of view of the molecular proportions, and nearly always also with regard to the weight. This predominance is most evident in No. XII, but wide areas of syenite-porphyry doubtless have the same characters as regards the feldspar, though the magnetite content is low. This is true especially of the rocks bordering the zone of magnetite-syenite-porphyry, which is represented by No. XII.

Concerning the dark constituents we find a feature, viz. the high content of magnetite, which is common to almost all analyses with one very evident exception only, the syenitic dike-porphyries. This appears very well at a comparison between the values of P and M in the american system. In the syenitic dike-porphyries P is very predominant, but in other analyses of the syenitic rocks the two groups are almost at balance, M being now and then predominant. But there also occur rocks tending to the same direction as the dikes, as for instance No. XI.[2] In the rocks of the most northerly part of the syenitic area this predominance of the magnetite group is most strong, as shown by No. XII. The fact ought, however, to be remembered, that this analysis does not represent a quantitatively subordinate phase but a rather widely distributed one, and that this character, as well as the predominance of sodium, is applicable also to other kinds of rock of the same region though of course on a smaller scale. Also among the quartz-porphyries the same feature is very pronounced, especially in No. XIII.

Some of the differences between the various analyses have been pointed out in the above. The relation between the alkalis shows sudden variations, as between No. VIII and No. IX; these belong, however, to the same dike and the specimens for analyses are taken quite near one another. The rock analyses from the region published before (Ns. II, V,

[1] This writer has, as is well known, calculated with two main kinds of igneous rocks, called the »Alkali-Reihe» and the »Kalk-Alkali-Reihe», but in the last edition (in 1907) of his »Physiographie der massigen Gesteine» he is obliged to give a third »Reihe», »Charnochit-Mangerit-Anorthosit».

[2] No. II (syenite) and No. X (dike porphyry) are very similar when classified according to OSANN's system, but the relations between P and M are very different, following the given rule.

VI and XIV) show much more soda than potash, while several of the new analyses have a greater weight of the latter.

The MgO content is in the syenitic group rather variable, even when not considering the dike rocks. The quantitatively less prominent substances, as TiO_2 and P_2O_5, also vary, especially the latter. The TiO_2 content has no relation at all to that of the iron oxides. CO_2 evidently occurs as calcite, which the writer does not consider as a quite primary constituent of the rocks.

As stated above, the Kiruna rocks are no true »Alkaligesteine». But in the two classification systems applied here we find them almost exclusively together with such rocks. Among those of OSANN's types that our analyses are most closely connected with, the following ones may be quoted here: granites: Quincy, Syene and Kammgranit; syenites and monzonites: Hedrum and Yogo Peak; liparites: Comende, Cerro de las Navajos and Mühlenthal; trachytes: Garkenholz; dacites: Porobbo. The group, even widely distributed within the Kiruna region, which is represented by No. I, is not similar to any of these types. In the american system the same characters are most prominent among the more basic rocks (Class II Dosalane). But with regard to the siliceous types the writer must point out, that our rocks are rather similar to the liparites of Iceland.

From reasons already given,[1] the writer has not used the name of keratophyres for the porphyritic rocks of the Kiruna region, though their chemical characters are very similar to some rocks called by this name. Among the dissimilarities to the keratophyres such as they have been described in the last edition of ROSENBUSCH's »Physiographie» there ought to be observed the high magnetite content of our rocks. Before, ROSENBUSCH classed all keratophyres among the »Alkaligesteine», with a great hesitation, however. But now he counts among them only those containing dark alkali-silicates, and regards the rest as »eine mehr oder weniger aplitische Spaltungsform der effusiven Kalk-alkali-magmen» (p. 1493). But he emphasizes the difficulty of deciding in each case to which of these groups a keratophyric rock belongs.[2]

Even when regarding the ore-bearing igneous rocks of Swedish Lappland as keratophyres, it does not seem very appropriate to call this vast

[1] p. VI.
[2] In the last edition (1910) of his »Elemente der Gesteinslehre», ROSENBUSCH is inclined to regard most keratophyres as lime-alkali rocks.

mass of intermediate and siliceous rocks an aplitic phase of a lime-alkali-magma.

In the charnockite series we have a new »Reihe», the extrusive forms of which are not yet described. They are of course very probably to be found among the various rocks now classified as keratophyres. A comparison between our rocks and those of the charnockite series is made difficult by the former being generally siliceous, while of the latter the more basic kinds are most well known. ROSENBUSCH characterizes [52, II: 1] the charnockite-mangerite-anorthosite rocks as a series, »die sich bei typischer Ausbildung chemisch durch das auffallende Zurücktreten der Eisenoxyde und der Magnesia, mineralogisch durch einen vorherrschenden eigentümlichen Mikroperthit und die Vorherrschaft von rhombischen und monoklinen Pyroxenen über Glimmer und Amphibole, sowie durch das Hinabreichen der Kalifeldspate und des Quarzes bis in sehr basische Gesteinsformen hinein charakterisiert». If we compare this description to what we have found to be the most pronounced characters of the Kiruna rocks, the importance of the microperthite is almost the only essential similarity. If future studies should show, however, that they really are chemically closely related to the rocks of the charnockite series and ought to be classed under it, the definition of the latter must evidently be quite another, and the limits towards the other two series, especially towards the lime-alkali-series, must be very undefined.

The magnetite-syenite-porphyry. A quite particular attention ought to be paid to the magnetite-syenite-porphyry, represented by analysis No. XII. In it the pecularities of the family are most strongly pronounced. As to the feldspar, such a predominance of the albite molecule has scarcely been observed before in any other than true alkali rocks. Still more astonishing is such a high content of iron oxides in an alkali-feldspar rock and their strong predominance over the magnesia. The existence of a magma with this composition is evidently of great consequence for the interpretation of the genesis of the great iron ores of the Kiruna region and of other ores of the same geological and petrographic characters. Those adverse to the theory which regards the ores as magmatic segregations from syenitic rocks have among other things also pointed out that syenitic magmas rich in iron do not exist and that the ores in question usually are very low in magnesia, contrary to the segregation ores of the basic rocks (gabbros, anorthosites, etc.) HÖGBOM in a report of 1898 [24] emphasizes that the magnetite ores of northern Ural are

accompanied by rocks composed entirely of alkali-feldspar and magnetite, the latter sometimes making up about 20 per cent of the rock. He regards this as a very strong reason for the application of the theory of magmatic segregation to these ores. This matter will be more closely discussed in a following chapter.

Among the specimens collected by HÖGBOM, there is a fragmental rock especially interesting in this respect. It chiefly consists of small sinuous or rounded pieces of rocks extremely rich in magnetite, which under the microscope are marvellously similar to some phases of our magnetite-syenite rocks, as for instance the brecciated form on Hopukka and the conglomerate pebbles from Pahtosvaara. In a slide of this Ural rock there are fragments representing all transition stages from a feldspar rock containing only a small amount of magnetite to ore with a few enclosed feldspars. The magnetite generally forms a sort of groundmass or basis in which the feldspars appear as angular white areas when the slide is examined in ordinary light. The structure is accordingly principally the same as in our rocks. It is evidently a fragmental rock of this kind, probably quite the same occurence, which afterwards has been described by LOEWINSON-LESSING [37] who also gives an analysis of the magnetite-bearing rock:

SiO_2	45,05
Al_2O_3	14,30
Fe_2O_3	16,93
FeO	7,13
MgO	1,30
CaO	2,81
Na_2O	6,14
K_2O	1,86
Loss at ign.	3.49
	99,01

LOEWINSON-LESSING calls the rock »ore porphyry». He considers it to have originated in such a way, that an extrusive syenitic magma has broken through and partly assimilated the magnetite ore mass of Wyssokaja Gora. The rock is in its composition rather similar to our magnetite-syenite-porphyry. If it is the same as the writer has seen under the microscope and which is mentioned above, or resembles the latter, the structure denies the hypothesis formulated by LOEWINSON-LESSING. This

hypothesis demands that the ore mass assimilated by the magma should be in a perfectly molten state and relatively equally distributed throughout the whole igneous mass, both these events taking place before the crystallization of the feldspars, as the latter almost totally lack inclusions of magnetite. The structure and the geological mode of occurence show, however, that these magnetite-bearing igneous rocks are at least practically superfically formed, which is also supposed by LOEWINSON-LESSING. It then seems to be very doubtful that the magma should have had such a strong power of assimilation. If, in order to explain the structure, one should suppose that the greatest part of the feldspars have been crystallized before the assimilation took place, the consequences will apparently be quite absurd. LOEWINSON-LESSING's hypothesis is therefore at any rate not applicable to the fragmental rock mentioned above.

The hypothesis is not more applicable to the similar rocks of the Kiruna region. To begin with, these are older than the ore bodies of the neighbourhood. They are then so intimately mixed — in a schlieric manner — with rock phases relatively low in magnetite, that, in order to interpret them according to the hypothesis in question, one should be obliged to presume the assimilation of numerous different ore bodies, together several times larger than the whole ore mass of Tuolluvaara. Many other reasons might be given, but those mentioned are surely strong enough to prove that LOEWINSON-LESSING's hypothesis is not applicable to our magnetite-syenitic rocks.

We must accordingly admit that alkali-feldspar rocks with a high primary content of iron oxides really exist, and even may occur as masses of geological importance.

Up to now there are, however, but few examples known. The greatest areas of such rocks are those between the north foot of Luossavaara and Hopukka. SUNDIUS has in the Kurravaara conglomerate of Pahtosvaara and Valkeasiipivaara found numerous pebbles, representing all transitions from magnetite-syenite-porphyry to ore with only a few feldspars, one such transition form is shown in fig. 68. Among these pebbles some show extrusive characters, while others have an almost eugranitic structure. These pebbles evidently represent an extrusion older than the above mentioned one, which is younger than the conglomerate. STUTZER [62] describes a morainic boulder of albite-magnetite rock from Ekströmsberg, about 30 kilometers west-southwest of Kiruna. He has kindly shown the writer the hand specimen and a slide, and they were quite in accordance

with the magnetite-syenite-porphyry south of Nokutusjärvi, which contains nodules and strings of albite. As the great pleistocene ice sheet in these regions has been moving from the southwest, the boulder cannot have originated from any hitherto known area of magnetite-syenitic rocks. From Gellivare Malmberg, HÖGBOM describes local highly magnetite-bearing phases of the syenites. Some of the rocks of the Painirova ore field also belong here, and many metamorphic feldspar-magnetite rocks described as magnetite-granulites by SVENONIUS and PETERSSON [53].

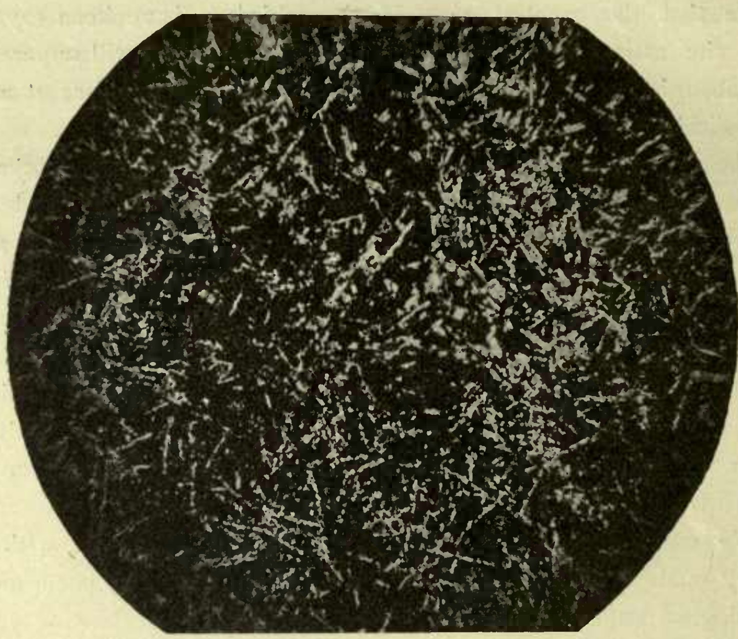

Fig. 68. Magnetite-syenite-porphyry. Pebble in the Kurravaara conglomerate of Pahtosvaara. (Specimen taken by SUNDIUS). Ord. light. Magn. 35 times. White is feldspar, black magnetite.

Outside the ore-bearing region of Swedish-Lappland the writer does not know any other example than the above mentioned one from Ural.

LOEWINSON-LESSING having already given a name to this porphyry type it may seem unnecessary to introduce a new one as the writer does. There are, however, several reasons for such a proceeding. The author in question did not know the geological relations of the rock he described, as he knew it only from a fragmental phase, and with his interpretation of its origin he was obliged to conside it as quite abnormal, its name

therefore being of little consequence to the petrographic nomenclature. This fact may perhaps have influenced the choice of its name. »Ore porphyry» is, it is true, a shorter name than magnetite-syenite-porphyry, but it is less expressive, it does not even say what kind of ore is meant and may also be misinterpreted in other ways. The word magnetite syenite is formed analogous to the common names augite-syenite, hornblende-syenite etc., i. e. using the name of the principal dark constituent as a prefix. In order to retain the uniformity of the nomenclature the writer will not use the otherwise rather expressive name of iron-syenite.

The limitation of the denomination magnetite-syenite must of course, as is the case with all similar classifications, be rather vague. It should comprise rocks consisting of alkali-feldspar (with only a very small proportion of anorthite) and of magnetite in a great quantity, as well as only small quantities of other minerals. It is *a priori* probable that phases rich in magnetite exist also among the quartz-bearing parts of the series. In the quartz-porphyries of the Kiruna region, especially in the hanging-wall rock of Kiirunavaara-Luossavaara, we find varieties of this character, which are not as rich in magnetite as the syenitic phases corresponding to them, but contain more than 10 per cent of this mineral.

Origin of the nodules.

The occurrence of nodules of magnetite, hornblende, apatite and titanite in the foot wall rock of Kiirunavaara has been mentioned as early as in 1890 by LÖFSTRAND. He seemed to have been inclined to explain them in the same way as other occurrences of apatite in these regions, viz. as phenomena, originated in connection with eruptions of gabbros or related rocks. Since then he did not speak on this question but, judging from his utterance concerning the Kiirunavaara ore body, he very probably changed his opinion.

Besides, these phenomena are only cursorily mentioned in the literature concerning Kiirunavaara until BÄCKSTRÖM in 1898 [42] gave an account of their composition and mode of occurrence and also expressed an opinion as to their origin, basing upon it a theory of the mode of formation of the great ore bodies. He mentions the minerals enumerated above and declares all of them to be younger than the surrounding rock, saying that hornblende and apatite are the oldest, magnetite coming in the next place and titanite last. He also mentions that the minerals fill thin fissures in the rocks. Of his observations regarding the mode of occurrence of the titanite in the compact rock the writer has already spoken. His interpretation of the nature of the nodules is evident from the following: »It is a common trait of the just described phenomena that minerals, which in normal igneous rocks crystallize first and before the feldspars, here occur as the very youngest products: filling fissures and vesicles or as pseudomorphoses — — — these phenomena seem to represent a phase of the volcanic action in this region, a phase that comes after the formation of the foot wall porphyries but before the formation of the hanging wall porphyries as the phenomena in question, as far as is hitherto known, are not seen in the latter.» In another place he points out that these phenomena are »probably of great importance to the explanation of the genesis of the ore body».

De Launay [8, in 1903] mentions the occurrence of »noyaux» and »amandes» of the minerals in question, and quotes Bäckström.

In 1904, at a meeting of the »Geologiska Föreningen» of Stockholm, Bäckström held a lecture on the ore fields of Ekströmsberg and Mertainen, both being located in the ore-bearing region of Jukkasjärvi, a report of it is entered in the proceedings of the society [6]. He mentions the occurrence of nodules of magnetite in the porphyries at Mertainen and other geological resemblances to Kiirunavaara, and maintains his opinion of the nature of these nodules. In the following discussion among others Holmqvist [22] took part, pointing out that these nodules are not amygdules in the usual sense of the word (the Swedish word »mandel» used by Bäckström is synonymous to the English amygdule) and that transition forms seem to exist between them and the dark minerals in the groundmass of the compact rock.

Stutzer [62] mentions the nodular structure in the foot wall rock in a few words, he regards the nodules as magmatic concentration products. »Diese kompakten Mandeln müssen hier magmatisch mit dem Keratophyr zusammen entstanden sein». (l. c. p. 605).

Lastly, the writer has touched upon this subject himself [14, p. 211] and especially called attention to the existence of red or white rings around the nodules, which fact renders it probable that their material is gathered from the immediately surrounding parts of the rock, the rings are then to be compared to »Kristallisationshöfe».

The material given in the precedent pages seems to be sufficient for forming a more definite idea of the nature of these phenomena than has hitherto been conceived.

When considering the distribution, we find the nodules almost exclusively in the »older» syenite-porphyries of the Kiirunavaara-Luossavaara district; they are very rare in the other rocks. In the former they occur, however, as well near the ore and the quartz-porphyry as farther west right up to the syenite, but never in the latter, not even in the fine-grained, porphyritic phases. They seem thus to be confined to true porphyries.

The mineral constituents are: feldspar (albite and microperthite), quartz, hornblende, biotite, titanite, magnetite, apatite, calcite, and quite locally tourmaline, muscovite, zircon and pyrite.

With the exception of the tourmaline and the muscovite and the quartz and calcite, which two last probably for some part are secondarily

infiltrated, all these minerals occur as primary constituents in the surrounding compact rock and have the same optical properties, a fact that, especially with regard to the feldspar, is remarkable. On Kiirunavaara there is microperthite, often twinned according to the Mannebach law, the plagioclase component showing a fine lamination (albite law) or cross-twinning (albite and pericline laws); near Nokutusjärvi it is »striped» albite without any perthitic laths. On the other hand we find in the nodules all the minerals of the compact rock with the exception only of the augite, which has been found, it is true, in certain structures of this kind (p. 40) but never in true nodules. In its place there occurs a hornblende, similar to the uralite resulting from the alteration of the augite. This fact may depend upon the conditions of temperature and pressure having been somewhat different in the nodules.

The relative ages of the different minerals are seen from the description, the writer will only emphasize that the feldspar generally seems to be the eldest, while the relations between the others vary and rather suggest a nearly contemporaneous crystallization.

The physical conditions for the crystallization of the nodule-forming minerals cannot, as a rule, have been very different from those applicable to the constituents of the compact rock, especially the feldspars seem to be a rather sensitive reagent in this respect. The order of crystallization between the various minerals is only a further development of the tendency, seen also in the syenite and partly in the compact porphyries, that the crystallization of the dark minerals has been delayed so as to make them contemporaneous with the feldspar or even younger. These structural features seem to indicate that the mass of the nodules, as regards the physical conditions, has been to some degree equal to pegmatites or other rocks crystallizing from aqueo-igneous solutions.

The question is: are the nodules a filling of cavities formed by the weathering out of a mineral, or of vesicles in a lava, or are they syngenetic with the rocks containing them? The first possibility needs not be much discussed. The varying shapes and often considerable sizes of the nodules, their total lack of angular outlines, the occurrence of the »embryonal» structures and many other details show that it is quite improbable. BÄCKSTRÖM regarded the rocks as lavas, the minerals of the nodules should have been deposited into their vesicles by post — or rather late — volcanic processes (»volcanic afteraction») especially by emanation of gaseous compounds of iron, titanium and phosphorus. As is already mentioned,

the quartz-hematite nodules in some of the rocks on Hopukka show characters making such an interpretation rather probable, but concerning the greater part of the nodules it is not likely to be tenable. It cannot explain the transition from the well defined nodules to the »embryonal» ones, which are nothing but structurally different phases of the ground-mass, nor why mineral individuals are so often common to the latter and a nodule. The likeness of the feldspars to the very species characteristic of the surrounding rock, that has been pointed out above, is also scarcely consistent with this view of the matter. Nor can it satisfactorily explain the light zones around nodule and veins; if owing their origin to the effect of the gaseous compounds on the solid rock these structures ought to occur much more extensively and also mark the entire way of the volcanic gases through the rock mass. Almost no nodules are connected with veins.

Thus there remains only the possibility that the nodules should be syngenitic with the rocks containing them. This hypothesis does not fall through on account of any of the causes alleged against the precedent ones, but on the contrary agrees with them entirely. The »embryonal» nodules denote an imperfect development of the nodular structure and are to be expected if one considers the latter to be formed during the solidifying of the rock. The light zones are found only around the nodules and veins containing dark minerals (magnetite, hornblende), it is then an obvious conclusion that the minerals, by the removal of which these zones have been formed, have concentrated in the nodule or the vein occupying the middle of the zone. These zones are in some respects analogous to the phenomena (formation of »scapolite-hornblende-fels») accompanying the apatite veins in the gabbros of southern Norway and the Gellivare region. In this »scapolite-hornblende-fels» surrounding the vein on both sides it is, according to VOGT [70], the iron minerals which first of all are removed by the action of the apatite-bearing solutions on the wall rocks.

It is mentioned above that nodules do not occur in the syenite. Certain structural features of this rock may, however, depend on circumstances analogous to those having caused the origin of the nodules, for instance the fact that the titanite and in part also the magnetite occur as mesostasis, filling the space left between the colourless minerals.

According to the opinion of the writer, these peculiar structures in the syenite, the nodules, etc., have been formed in the following way:

The syenite magma was at its eruption rich in water and in some mineralizers in a proper sense, principally fluorine. Some of the constituents of the magma, as the compounds of titanium, remained in solution longer than the rest of the magma (chiefly silicates). At the crystallization of the latter, this remaining solution filled the spaces between the crystals already formed and deposited the dissolved substances (mostly forming titanite) which thus formed mesostasis to the other minerals. The magnetite was also in solution for a long time but has crystallized before the titanite and before the feldspar was definitively limited. But the pressure was not strong enough to keep these, at least partly, volatile substance in the places given them by the feldspar mass. Here and there they attacked the surrounding feldspars and replaced them in part, the titanite in this manner passing into the third and second types.

In the porphyritic rocks the pressure was considerable lower, the titanite therefore occurs there exclusively in the shape of the second type. The water and the substances dissolved in it accumulated around certain centra as has been the case in vesicular lava rocks; these concentrations have surely had the shape of drops and constitute the nodules. The effect of the water has partly been such as to lower the temperature and to some degree alter the order of the crystallizing minerals and has partly been quite mechanical, the pressure having been the cause of the cavities, which form the greater or smaller part of many nodules. Because of these cavities the nodules may often be regarded as true vesicles. The physical conditions during the crystallization of the mineral constituents might at the beginning have been practically of an igneous character, but it is possible that the process sometimes has continued for so long during the cooling of the rock that the last crystallizing minerals have been deposited under almost quite aqueous conditions. The »embryonal» nodules are doubtless quite igneous, while the calcite and the quartz may rather be aqueous, but it is, of course, difficult to determine, whether these two minerals are not for some part of entirely secondary origin.

The light zones have probably been formed already before the solidification of the rock, but it is not impossible, that the removal of the dark constituents has continued for some time after it.

Some of solutions were free and penetrated the rocks, forming »skeleton titanite» as has already been mentioned. They accumulated especially on the planes of weakness developing in the solidifying rocks,

from which they influenced the same, at last coating the planes with a substance like that in the nodules. *The nodules are consequently concretionary bodies in the porphyries; they have crystallized under conditions passing form igneous (magmatic) to aqueo-igneous and show a transition to the normal groundmass of the rocks on one hand and to true vesicles on the other hand.*

The difference between this view and that of BÄCKSTRÖM is accordingly above all that the writer considers the nodule-forming minerals as much more closely connected with the containing rocks than the other hypothesis implies. This difference does perhaps not seem a very considerable one, but it is of a great consequence concerning the mode of origin of the ore bodies. The explanation of this great problem made by BÄCKSTRÖM and defended and developed by DE LAUNAY among others is ultimately based on BÄCKSTRÖM's considering the nodule-forming minerals as products of sublimation processes during the interval between the extrusions of the foot wall porphyries and of those forming the hanging wall.

In connection with many kinds of rock of different structure and chemical composition there have been described phenomena, which as regards their mode of origin are more or less similar to these nodules. The resemblance between the development of the titanite in our syenite and in the »spotted granites» of the Pyrenées and of Stockholm is already stated (p. 8). The nodular granite from Pine Lake, Ontario, described by ADAMS [1], shows sphæroidal bodies with pneumatolytic characters (bunches of tourmaline, etc.). BÄCKSTRÖM [5] has described the beautiful orbicular granite from Kortfors, Sweden. The sphæroids have been drops segregated from the magma and growing from without and inwards. The dark minerals have accumulated most near the surface, in the centre there is a granophyric intergrowth of microcline and plagioclase with quartz, the latter making up about 10 per cent of the mass. He supposes that these drops with regard to their physical conditions have been similar to pegmatites.

The apatite veins confined to more or less femic rocks (gabbros, »pyroxenites») might also be alleged, but they have rather aqueous characters and are not so closely connected with their igneous mother rock. For comparison see the lucid account of the geology of these veins given by VOGT [70]. With regard to the physical conditions

even the lithophysæ seem to be analogous to the nodules, but no removal of substance dissolved in water seems to have taken place at their formation.[1]

The amygdules of zeolithes in the natrolithe-bearing phonolite at Aussig, Bohemia, described by HIBSCH [20], show that the very mineral that has crystallized last of the constituents of a vesicular rock, also may develop in its vesicles. The cavities in the dolerite at Londorf, described by STRENG [59] may also be referred to as phenomena somewhat similar to the nodules.

In the region of Kiruna, nodules occur especially in the »older» foot wall porphyries, and are very rare in the quartz-porphyry. They occur in other places as well within the ore-bearing region of Jukkasjärvi and are especially well developed at Mertainen.

As the knowledge of the physico-chemical laws of the crystallization of minerals from magmas has been much enlarged during the last years, several scientists have been inclined to reduce the importance of the magmatic waters and to minimise the influence of halogens and other substances dissolved in the magma, especially with regard to differentiation processes.

Such is for instance the case with VOGT who in a very considerable degree has increased our knowledge of these phenomena. He considers [70] but with some hesitation with regard to the details, that the apatite veins genetically connected with femic rocks are a result of extraction of diverse substances, among others phosphorus, from the molten magma. This extraction is caused by the action of hydrofluoric and hydrochloric acid. But he believes all molten silicates to be unlimitedly soluble in each other and accordingly rejects the liquation — or drop — hypothesis which BÄCKSTRÖM [5] has made use of in order to explain the origin of orbicular granites. BÄCKSTRÖM bases this hypothesis especially on studies of the granite of Kortfors mentioned above. In these sphæroids, the last crystallizing constituents occupy the centre, the dark minerals having concentrated towards the periphery. If one does not want to suppose a quite reverse order of crystallization, one must presume that the restricting plane of the sphæroid has been a distinct border, towards which the first crystallizing minerals have gathered, i. e. the sphæroid should have been lying as a separate drop in the rest of the magma. VOGT [74] shows, that many other occurrences of orbicular granite, for instance those of Kangas-

[1] IDDINGS [26].

niemi, Stockholm and Virvik, can be explained according to well-known laws applicable to aqueous solutions. But the granite of Kortfors is evidently an exception in this respect, and as yet the liquation hypothesis ought surely to be maintained with regard to the sphæroids that have grown from the outside and inwards.

What one might think of the orbicular granites may not be of very great consequence to one's opinion of the nodules, but on account of the analogies that doubtless exist between the former and the latter of the Kortfors type,[1] it seemed to the writer that the question ought to be taken some notice of here. We must, however, point out that VOGT is inclined to attribute a great influence to the water dissolved in the magma as regards differentiation phenomena.

[1] These granites appear, however, to be very rare.

Survey of the rock metamorphism in the region.

As appears from the petrographic descriptions, the igneous rocks of the Kiruna region are as a rule only very slightly metamorphosed. Though they have been subjected to considerable tectonic disturbances (they stand almost vertically) there are seldom seen but vague traces of regional metamorphism. There exist only very insignificant examples of true contact metamorphism as well, if we leave out of consideration the scapolitization which perhaps ought to be classed there, but the origin of which is still unknown. The silicification described in a previous chapter might perhaps be regarded as a kind of contact metamorphism, and the uralitization has also been interpreted in such a way by STUTZER [62].

Though the regional and the true contact metamorphism are of no great interest by themselves, we must, however, dwell upon them as they, at least in some degree, may have changed the primary characters of the rocks, especially the structure; a neglecting of these factors might therefore be the cause of wrong conclusions with regard to the mode of eruption of the rocks, etc.

When regarding first the syenite and the porphyries of the western district, the optical homogeneity of the (surely primary) quartz grains shows, indeed, that these kinds of rock not have been subjected to any very strong pressure after their crystallization. Some rock phases may perhaps have undergone a weak metamorphism, this being the case of the most fine-grained ones — especially in the quartz-porphyry, see p. 135 — which probably have been solidified as glass, and some sphærulitic varieties. In some isolated places the regional metamorphism has, however, left distinct marks in the shape of a plainly visible schistosity in the rock. This has for instance happened with a narrow zone on northwestern Kiirunavaara, extending near the ore and parallel to it. Here the rock

contains new-formed quartz, calcite and biotite. Within the easternmost parts of the quartz-porphyry on Haukivaara there is also seen a distinct schistosity with an almost north-southerly strike, the dip being steep to the east. Muscovite (sericite) is the most conspicuous new-formed mineral there.

Of contact metamorphism there are only still more insignificant traces to be found in the same district. Slides showing the contacts between dike rocks (dark syenite, syenite-porphyry, quartz-porphyry) and syenite show no signs of metamorphism in the latter. The local amphibolization of the foot wall rock of the Kiirunavaara ore body must, however, evidently be regarded as a case of contact metamorphism caused by the latter. It is also probable that some structural features in the foot wall rock, immediately adjacent to the ore, may have the same origin.

Among the rocks of the eastern district we find an indisputably metamorphic phase, the even-granular rock of Sakaravaara described p. 198. The latter is probably a case of contact metamorphism (see p. 202). The metamorphism in this district seems for the rest to have been very insignificant (the quartz phenocrysts often being optically homogeneous) but the amphibolites, which at least partly have a secondary structure, and the scapolite-biotite rock ought to be taken notice of. The structure of the quartz-bearing porphyries shows a great similarity to a secondary one, but it is nevertheless possibly primary. If it should be secondary, a contact influence must evidently have been the cause of the metamorphism, as the little damaged quartz phenocrysts show that the latter cannot be due to pressure.

It may thus be regarded as a fact that the igneous rocks of the Kiruna region as a rule still retain their primary structure, the chief exception being that some, now very fine-grained, groundmasses probably have been originally glassy.

The silicification and the related phenomena are so exhaustively described in a previous chapter that we need not dwell upon them here.

The formation of uralite and other secondary amphibole.

In the above we have described how in Kiirunavaara the primary augite of the syenite, and especially of the porphyries connected with it, has been replaced by hornblende to a great extent, and we have pointed out, that the distribution of this metamorphism is rather peculiar, the augite in some parts of the mountain being quite intact, while it in others is quite uralitised. In the syenitic dike-porphyries the uralitization is much less radical.

Though all the stages of this process can be studied, the writer has not been able to find in any quite certain case, that substance has been segregated during it. It appears accordingly to be a paramorphose. But most writers seem, however, to be inclined to regard it as a real pseudomorphose, though the by-products scarcely have been studied [77 I p. 316 and following]. But the writer has not been able to show any products of this kind in cases of a very evident »titanitization» either. The decision is also rendered difficult by the fact that the hornblende substance is not restricted to the original augite form. In the kind of rock in question the first stage of this alteration is, on the contrary, the development of hornblende needles, extending far outside the latter. See fig. 2.

A replacing of feldspar substance must evidently have taken place here. This is especially quite evident with regard to the uralite in the groundmass of the porphyries, which consists of such needles in sparse clusters, their shape evidently being very different from that of the original augite grains. Sometimes the hornblende also appears to have the shape of small sheaves, no augite having been the cause of their origin; as for instance in the border zone of dike No. 5, which is very rich in hornblende. The phenomenon shown in fig. 12 might also be remembered here. All this is what is generally called »gewanderte Hornblende», the

mode of origin of which is not very well known as yet. It is really very extraordinary that such thorough alteration processes should not be accompanied by any by-products.

The development of uralite has as a rule been regarded as caused by changes of pressure especially in connection with folding processes. But there also exist many examples of its occurring as a product of contact metamorphism, as such a one may be regarded the contact zone (scapolite-hornblende rock) of Norwegian and north Swedish apatite veins occurring in gabbro. Regarding the last-mentioned case, VOGT [70] has considered altered conditions of pressure (but not regional metamorphism) to be the cause of the process, while HJ. SJÖGREN is of the opinion that it depends on the rock's having been drenched with superheated water. The difference between the opinions of these two writers is perhaps not so very great. Both of them regard the process as a paramorphose.

As has already been pointed out in precedent chapter, there exist in our kinds of rock some phenomena reminding us of these contact zones along the apatite veins. It might consequently be possible that the uralitization also in the case in question should depend on the causes given above, most probably on the circumstance that hot gases and solutions have affected the rocks. This should also explain why no such regularity has been found in the distribution of the process, as might have been expected if it had depended on folding processes. It is also worth noticing that the uralitization is so much weaker in the syenitic dike-porphyries than in the other, only very little older, porphyries.

Mode of eruption of the igneous rocks.

A question of great importance is: are the porphyries intrusive or extrusive rocks? LUNDBOHM and BÄCKSTRÖM [42], who were the first to study this matter, regarded the agglomeratic, conglomerate-like band on Luossavaara as a tuff and the nodules as vesicles, after the solidification of the porphyry filled with minerals. The concordance with the sedimentary rocks of the region was to them another reason for regarding the porphyries as representing lava flows (of unknown number); during the time between the eruption of the syenitic rocks and that of the quartz-porphyry there should have taken place, according to BÄCKSTRÖM, very strong emanations of gaseous compounds. DE LAUNAY [8] has quite the same views. STUTZER [62] is of quite another opinion, he considers them to be »Gangporphyre». The writer cannot interpret this expression otherwise than that the porphyries should be partly intrusive laccolites, partly dikes. As the writer in this matter almost agrees with LUNDBOHM and BÄCKSTRÖM — except with regard to the above mentioned pneumatolytic processes — he must here examine the reasons alleged by STUTZER in favour of his opinion. He says (l. c. p. 601):

»Für Gangporphyr spricht:

1. Der beobachtete Übergang von Syenit in Syenitporphyr.

2. Das Auftreten typischer kleiner Porphyrgänge im Porphyr, z. B. der kleine Felsitgang bei Landshöfdingen (Nordseite, liegender Porphyr).

3. Die Einschlüsse von älteren Porphyr und Magnetit im hangenden Porphyr.»

Of these three points the first one only is of any importance. It must be remembered, however, that at the extrusion of huge igneous masses at a time — and this is, according to the opinion of the writer, the mode of eruption of the syenitic rocks, at least at Kiirunavaara, — the physical conditions during the crystallization could in the bottom parts not have been very different to those existing in a rock intruded

under a covering of older ones, some hundred meters deep. That the eugranitic structure can develop in the last-mentioned case, is shown by BRÖGGER among others, and that it really may develop in slowly cooling parts of an extruded magma is proved by the phenomena in Lugano described by HARADA [18]. Further on I may point out, that in the ore mountains of northern Ural coarse-grained syenite occurs in a schlieric alternation with fine-grained or almost dense phases, the whole series being probably extrusive or at least formed very near the surface.

With regard to the second point, there exist, as has been described above, numerous large dikes in the district, but in this case they prove nothing. Dikes are very often seen in the crater walls of volcanos. The inclusions of syenite-porphyry and ore in the quartz-porphyry only show that the last mentioned is younger than the other two. Even an extrusive rock must have cut older rocks somewhere.

STUTZER writes further:

»Für die Annahme des Vorhandenseins eines älteren Nebengesteins spricht:

1. Ein grosser mit Eisenglanz imprägnierter Quartzitblock in der Eruptivbreccia am oberen Teile des östlichen Luossavaara. Zur Zeit der Bildung dieser Breccia muss also ein mit Eisenglanz imprägnierter Quarzit als Nebengestein vorhanden gewesen sein.

2. Rote Ortoklasgänge, die am unteren Teile des östlichen Luossavaara Phyllite und ältere Quarzite durchziehen und wohl sicher mit der Porphyreruption in Zusammenhang stehen.

3. Apatit-Magnetitmassen, die am unteren östlichen Teile des Luossavaara in die Phyllite hineingebrochen sind.

4. Das zweite, östliche Magnetitvorkommen des Luossavaara, das in den Phylliten auftritt.

5. Das Auftreten der Magnetitgerölle im Schiefer am östlichen Abhang des Luossavaara. Letzteres spricht für eine Trennung des Haukischiefergruppe in eine jungere und ältere Abteilung. Bei Annahme eines Ergussporphyres und einer darauf folgenden sedimentärer Ablagerung der Haukischiefer wäre die Abrollung dieser Magnetitmassen höchst auffallend . . . .

6. Die stark gefalteten Phyllite, die sich auch als Konglomerateinschlüsse in dem jüngeren Quarzitsandstein als gefältete Phyllite in flachen Schieben finden, sprechen für einen grösseren Zeitinterwall zwischen der Bildung dieser beiden Gesteine . . . .»

The quartzite fragment mentioned under No. 1 is surely the same as described by the writer on p. 136. No rock altogether identical with the latter is known in the region, but quartzite pebbles are found as early as in the Kurravaara conglomerate. This fragment therefore cannot be considered as proving the quartz-porphyry of Luossavaara to be younger than its hanging wall rocks.

The orthoclase-dikes must be those mentioned on p. 173. They are

intimately connected with the quartz-bearing red rock (Rektor porphyry type) of eastern Luossavaara and do not cut phyllite and sedimentary quartzite but dark porphyries of syenitic composition and quartzite rocks resulting from the silicification of quartz-bearing porphyries. The magnetite ores rich in apatite occur only in rocks of igneous origin.

What STUTZER means by No. 5 is quite incomprehensible to the writer. He draws the conclusion that the ore must be of sedimentary origin if the porphyries are extrusive. Somewhat later, however, he discusses the possibility that it might be a lava flow (but does not think it probable). The phenomenon described under No. 6 has not been seen by the writer, and ZENZÉN, who has studied the rocks in question has informed that he has not seen it either. Most probable is, that a later pressure on the conglomerate has given the phyllite fragments an appearance resembling »Phyllitfältelung». We must point out, however, that ZENZÉN thinks that the Hauki complex may be composed of two groups, separated by an unconformity.

The reasons alleged against the extrusive nature of our rocks are consequently of no importance.

Within the huge mass of syenite and »older» syenite-porphyries of Kiirunavaara no sharp contacts have been observed. The structure of the syenite shows that it has solidified somewhat below the surface. There is evidently present here an extrusion of an immense quantity of syenitic magma at a time, probably from a fissure similar to the »gjas» of Iceland. We do not know much about the extension of the extrusive body, but being relatively siliceous it has probably formed a low cupola and not an even bed. It must be admitted that the structure of the porphyries only seldom indicates really superficial conditions during the solidification. It is, however, as has already been pointed out in a precedent chapter, possible that the structure of the groundmass sometimes has been changed by metamorphic processes. The fluidal streaking, the development of sphærulitic structure and of open nodules denote rather an extrusive than an intrusive rock. The place where the syenitic magma has broken through older rocks and spread over the latter is probably southwest of the south end of Kiirunavaara. There is, it is true, not a single rock exposure in the vast marshes, but the study of the moraine boulders on Jägmästaren and in the vicinity, which to a great extent must originate from the entirely covered area to the southwest, shows among them numerous boulders of the Kiirunavaara syenite with numerous enclosed

fragments of a fine-grained, massive rock of a greenish gray colour. There is scarcely seen a single block without such fragments, but many boulders of the greenish gray rock interwoven with small dikes of the syenite. The latter has its usual structure and grain even in dikes of only a finger's breadth. The gray rock is made up of feldspar, probably albite, rather much bluish green hornblende, biotite, magnetite and some titanite. Fragments of this kind are present very sparingly in the syenite of northern Kiirunavaara, and the distribution of the above mentioned moraine boulder shows very plainly that the syenite must break through the gray rock southwest of this mountain. It is thus very probable, that we here have the place of extrusion of the syenite body. Rocks similar to the fragments have been found by SUNDIUS west of lake Luossajärvi.

Between Luossajärvi and Nokutusjärvi the phenomena are as a rule analogous to those on Kiirunavaara, with the difference only, that no syenite is exposed. It is possible that these porphyry masses are connected with the syenitic rocks of Kiirunavaara, in which case the extrusive body should be of very large dimensions. On Hopukka, as well as on Välivaara, there occur strongly pronounced lava rocks. The relations between the porphyries of Pahtosvaara and those of Kiirunavaara are unknown.

The quartz-porphyry further on shows more pronounced extrusive characters than the syenitic rocks. It is difficult to determine whether it is a single lava body or is composed of several different beds. The shape of the porphyry mass in Porfyrberget, where large points of porphyry project into the Hauki complex, is secondary and due to orogenetic movements, as shown by the examinations of the Hauki complex and the contacts. It has already been mentioned, that the agglomeratic zones and the distribution of the ore fragments are explained in favour of the latter alternative. The interval between these different lava flows must, however, have been very inconsiderable, and one might certainly without making a great mistake regard all this porphyry mass as formed at a time.

Afterwards followed the eruption of the peculiar red rock (Rektor type) of Luossavaara, and then the period of very intensive fumarolic and hydrothermal action, resulting in silicification and deposition of hematite ores. For some time then continued eruptions of syenitic lava (porphyries of the Hauki complex) alternating with the deposition of tuffitic sediments and fumarolic action of the kind just mentioned, causing the

formation of the lean Hauki hematite ores among other things. Small eruptions of quartz-porphyry (Nokutus type) also took place.

The syenitic dikes are, as has been mentioned before, partly older, partly younger than the ore of Kiirunavaara and the quartz-porphyry. With regard to the quartz-porphyry (granophyre) dikes on the same mountain we only know that they are, at least partly, younger than the ore.

The geological mode of occurrence of the rocks of the eastern district is too little known to allow any definite conclusions to be drawn in these respects, but it seems to be very probable that the bulk of them represent large outflows of the same character as those pointed out in the western district.

Genesis of the iron ores.

How interesting as may be the Kiruna rocks with regard to their chemical and petrographic characters and their mutual relations, it is, however, the possibility of gaining an explanation of the genesis of the ores of the region by studying them, that above all makes such a study interesting. Every scrap of knowledge of the geology of the region being of value to a proper judgement of this question, the writer has put off the treatment of it until in this last chapter, when all he has to offer in the way of material has been given already.

The literature concerning the Kiruna ores has before to a great part consisted in theoretical discussions and contained only relatively few geological dates. The latter, which, at least, ought to be the basis of the discussion, are limited to the work of the official commission of 1875 which on account of the short time etc. was very inconsiderable compared to the difficulty of the subject, examinations by Fredholm, Löfstrand and others (most of them for the Geological Survey of Sweden) in the eighties and the beginning of the nineties, LUNDBOHM's and BÄCKSTRÖM's works in the late nineties and STUTZER's in 1906. Among these works, those of LUNDBOHM and BÄCKSTRÖM are the most important ones[1] and that of STUTZER is valuable especially on account of the attention he paid to the structures of the ores.

The members of the commission of 1875 regarded the wall rocks of the Kiirunavaara-Luossavaara ores (Tuolluvaara was not discovered until in 1897) as sedimentary hälleflints, and the ores as an interstratified sedimentary deposit. In 1889 TÖRNEBOHM [65] published the results of the microscopical examinations made by him of rock specimens taken by WIBEL, and the eruptive nature of the wall rocks was thus known. In 1891 the same author [66] writes, that the iron probably originated from the older (foot wall) rocks, the ore content of which had been concen-

[1] These authors have only published a short but very much to the point description [42], and besides we have LUNDBOHM's work on the ores [41] mainly from an economic point of view.

trated through chemical and mechanical processes. LÖFSTRAND [43], in the same year, spoke against this explanation, evidently being of the opinion that only chemical processes had been in activity. He regarded the apatite not as a primary constituent of the ore but as a later deposit; the incorrectness of this view was proved by LUNDBOHM. In 1893 [56] HJ. SJÖGREN counted Kiirunavaara among ores formed through metasomatic alteration of silicate rocks by iron-bearing solutions.

LÖFSTRAND explained his opinions more closely in 1892 [44]. Among other things he wanted to propose, beside the Taberg type of segregation ores, another one, generally occurring as dikes or dike-like bodies, which comprehends about the same as LEITH's »pegmatite type» [36]. To this type he also refered, among others, the Kiruna ores. Though it is not easy to understand quite clearly from LÖFSTRAND's statements how he imagined the genesis of the ores, one gets an idea of his views by his giving three possibilities to choose between: pneumatolytic dike, magmatic dike or schliere. VOGT in the same year [68] counted Grängesberg among the ores of sedimentary origin, but placed Kiruna, Gellivare and the Norwegian apatite-bearing ores (Solberg—Lyngrot) in one group, concerning which he did not want to express a quite decided opinion.[1] In 1898 LUNDBOHM and BÄCKSTRÖM published a short communication of their investigations [42]. Basing his view on his opinion of the nature of the nodules (see p. 236), the latter arrived at the result, that the ores are of pneumatolytic origin. Almost at the same time appeared HÖGBOM's essay on the iron ores of the syenitic rocks of Ural [24], where he describes these ores as products of magmatic differentiation and also shows that the same explanation probably holds good of the Kiruna ores; as a fact the latter appear in similar eruptives and show the same general characters as regards composition and structure. HÖGBOM bases this opinion on the composition and mode of occurrence of the ores, and on the existence of syenitic rocks rich in magnetite, proved by him. The essay is of great importance as it is, after LÖFSTRAND's rather vague suppositions, the first expounding of the magmatic theory in order to explain the north Swedish ores.

DE LAUNAY [8, 1903] agrees with BÄCKSTRÖM's opinion, which he explains more closely. During the time between the eruptions of the

[1] In a paper published during the printing of these pages, VOGT embraces the magmatic theory for all these apatite-bearing ores (»Über die Rödsand Titaneisenerzlagerstätten in Norwegen». Zeitseln. f. prakt. Geol. Bd. XVIII, 1910, p. 59).

great beds of porphyry he supposes emanations of iron chloride to have taken place, reacting with the water (the eruptions should, according to him, have been submarine) to form hematite, which through a later metamorphism was reduced to magnetite. As another alternative DE LAUNAY imagines the deposition as sulphide, with a following reduction. He rejects HÖGBOM's theory, laying emphasis upon the on the whole sharply defined contacts between the ores and their wall rocks.

In 1904 BÄCKSTRÖM [6] applied his pneumatolytic theory to the ore fields of Mertainen and Ekströmsberg. He gives an exact statement of his opinion of them and of the Kiirunavaara-Luossavaara group, writing as follows (l. c. p. 182). »The iron ores occurring in association with effusive rocks should accordingly have obtained their material from below, during the last stage of the volcanic activity, in the shape of compounds of iron, phosphorus and titanium (chiefly chlorides and fluorides), emanating as gas or as superheated solutions. In the surface regions these have been decomposed by the water and the silicates they have been in contact with.» HOLMQVIST [22] regarded this theory as scarcely probable with regard to Kiirunavaara and Ekströmsberg on account of the regular shape, the size and purity of the deposits; he seems to be rather in favour of some sedimentary point of view.

In 1906 STUTZER [60] published a short essay on the Kiruna ores, based on a hasty visit to the place and on the study of the literature at hand (especially DE LAUNAY). He regards the ore bodies as »eine gewanderte magmatische Ausscheidung», i. e. as a magmatic dike, genetically closely related to its wall rocks.

During the discussion of the genesis of our iron ores, that took place at the »Geologiska Föreningen» of Stockholm in May, 1906 [76], the Kiruna deposits were also discussed. HJ. SJÖGREN, who opened the discussion, placed as one group the ores of the soda-porphyries which he does not believe to have originated through a pneumatolytic sedimentation as has been supposed by BÄCKSTRÖM and DE LAUNAY, especially with reference to the related phenomena in Ural and Mexico. He embraces the epigenetic theory without further explanations. HÖGBOM does not think, it is true, that the question of the Kiruna ores is solved definitively, but stands up for the magmatic theory and answers remarks made upon it. BÄCKSTRÖM persists in his former opinion. When TÖRNEBOHM holds forth, that the hanging wall porphyry in Kiirunavaara contains inclusions of ore fragments, SJÖGREN answers, that the ore body

may be epigenetic in relation to some porphyries but not to all;[1] he quotes STUTZER. LUNDBOHM judges it rather unsuitable to discuss the matter, when so few facts are known.

In 1906 STUTZER made examinations of most north Swedish iron ores of this type, and he arrived at the result [62] that they are all magmatically formed, though pneumatolytic processes have also sometimes played an important part. He discusses the Kiruna deposits on the presumption that the wall rocks are »Gangporphyre»; it makes, however, no difference that they are, as already shown, effusives. STUTZER sums up his opinions as follows: »Die Magnetite der Umgegend von Kiruna hängen genetisch aufs engste mit den sie begleitenden Keratophyren zusammen. Wie die Porphyre sind sie auf magmatischem Wege entstanden, und relativ gleichzeitig mit diesen nach oben durchgestossen».

As to the result of the discussion held up to now may be set down, that several theories are quite annihilated, as for instance the mechanical sedimentation and the chemical sedimentation in analogy with bog ores. The metasomatic replacement may also surely be regarded as rejected, though GREGORY [16] seems to be inclined to ascribe at least some importance to it.

After the description of the ores and the surrounding rock given here, the impossibility of this theory must surely be obvious. We ought especially to emphasize the similarity between the ore bodies and the apatite dikes, the fact that the paragenesis magnetite-apatite and the structure are irreconcilable with this view and that the limits of the ore bodies are so well defined.

A theory, which has never been maintained by anyone is that the ores should be veins of aqueous origin similar to the ones carrying mainly sulphide ores in a gangue of quartz, carbonates or baryte. STUTZER [62] has, however, discussed this possibility. He emphasizes the absence of the common vein structures and of the gangue minerals just mentioned. Magnetite is moreover very rare on such veins, and a metamorphism of siderite or hematite into magnetite ought also to have left some traces in the wall rocks. STUTZER therefore finds this theory quite absurd.

The theories remaining after this thinning and which, according to the opinion of the writer, are worth to be taken notice of, may be divided into two groups.

[1] On account of a misunderstanding of the ore breccia at Grufingeniören, SJÖGREN thinks that the ore is not restricted to the boundary between the two main porphyry types.

HÖGBOM and STUTZER are both of the opinion that the ores are of magmatic origin; the former regards them as schlieren, while the latter regards them as »magmatische Gänge», only little younger than their wall rocks and genetically connected with them. LÖFSTRAND was, as may be remembered, the first who dared to express an opinion in favour of the magmatic point of view, but how he explained the matter in detail is not known.

BÄCKSTRÖM distinguishes between two main outflows of lava at Kiruna, and regards the ores as deposited during the time between their eruptions, through the decomposition of volatile compounds of iron, phosphorus, etc. DE LAUNAY is in the main points of the same opinion, he supposes, however, that the deposition should have resulted in hematite (or perhaps pyrite), which through secondary processes, chiefly due to pressure, has been altered to magnetite.

The writer agrees absolutely with the magmatic point of view, but with regard to details he is neither altogether of HÖGBOM's nor of STUTZER's opinions. Before discussing the nature of the differentiation process, which has caused the origin of the ores, and questions related to it, he wants to give those traits of the ores, in their mineralogical composition, their structure and geological mode of occurrence, that are determinative of his view.

When regarding first the minerals of the main ore bodies, we find that all the following may almost with certainty be regarded as primary constituents: magnetite, hematite, apatite, augite, amphibole (chiefly hornblende), titanite, ilmenite, biotite, zircon and orthite, and tourmaline quite locally near the contacts. All these minerals may crystallize from magmatic solutions and occur as primary constituents of the igneous rocks of the region.[1] Magnetite is abundant in the latter, hematite, on the other hand, is rather seldom seen. Even in the ore bodies it is not, it is true, widely distributed as a primary constituent and occurs in that character chiefly in veins being, with regard to their origin, somewhat different from the main mass of the ore. The same is true of the ilmenite. Apatite is on the whole common in the rocks and is locally very abundant. The species of augite occurring in the ore has the same optical properties as the one seen in the syenite and in the porphyries, the same is the case of the hornblende. which is mostly of uralitic nature. Titanite

[1] The tourmaline, however, may perhaps not be regarded as a primary mineral in the porphyries.

is much less common in the ores — apart from the contact zones — than in the rocks. In the latter it occurs as a rule as one of the last crystallizing minerals, replacing the older ones. In analogy to this it occurs in the ores chiefly in drusy cavities or in their immediate neighbourhood.

The mineralogical composition of the ores is thus much in favour of the magmatic point of view. This is still more the case with the structural features, which, according to the view of the writer, are the most decisive proof. In the relation between the two main constituents, the magnetite and the apatite, there is as a rule nothing inconsistent with this theory.

The occurrence of a beautiful trachytoidal flow-structure in the apatite concentrations cannot be explained otherwise than by supposing that the apatite should have been in a molten state in the same way as for instance a trachyte before crystallization. Anyone who had not studied the matter closely, might perhaps think that this beautiful structure is a result of a later metamorphism. This is, however, quite impossible. Even if one would suppose that the ore body had undergone such a strong metamorphism, while the wall rocks were still quite intact, there is the difficulty of explaining why the apatite grains at the recrystallization have been arranged in this manner. A glance at fig. 41 may surely be sufficient for showing the impossibility of such a supposition. Nor is this proof to be explained away by ascribing to the apatite concentrations within the ore a different mode of occurrence than to the rest of the latter. The intimate relation between the two has already been pointed out.

The skeletons of magnetite in apatite may also be regarded as a very strong proof. The similarity between them and the phenomenon shown in figs. 23 and 24 ought especially to be emphasized, as it is evident from it that this skeleton structure must be regarded as a true magmatic one.

The structure of the ore phases containing augite or hornblende is also that of an igneous rock, the silicate crystals being in part corroded and lying in an ophitic manner in the magnetite groundmass. It is difficult to understand, how the pneumatolytic-sedimentary or any other theory except the magmatic one proposes to explain these phenomena. I also ought to state the schlieric inhomogeneity of the ore, and the pecularities of the distribution of the apatite already pointed out by STUTZER.

We find, however, in the ore, features quantatively of secondary importance, which might seem to be in favour of some of the other theories, e. g. the pneumatolytic one. The apatite is a mineral which often, for instance in pegmatites or in »vugs» in granitic rocks, occurs together with tourmaline, topaze, fluorite, tin ore, etc., i. e. in a typical pneumatolytic association. Its content of fluorine or chlorine also shows very plainly that mineralizers have contributed to its formation. We must remember, however, that it is much distributed in normal igneous rocks as one of the first crystallizing minerals, in which case it must be regarded as magmatically formed. With regard to the apatite dikes of the quartz-porphyry it has already been stated that they, in spite of their partly pneumatolytic characters, must have crystallized under almost magmatic conditions. In a still higher degree this holds true of the apatite masses within the ore bodies, which lack such characters. We have just now pointed out how even the structure of these apatite concentrations proves the correctness of the magmatic theory. It stands quite differently with the more or less drusy hematite and ilmenite veins and the titanite crystals lining cavities in the ore mass. They have probably originated through the decomposition of gaseous compounds and are consequently of pneumatolytic origin. Even the local presence of tourmaline in the ore near the contacts indicates the influence of mineralizers.

The »stratified» ore is the only feature in favour of the sedimentary theory and, at least at first view, much against the magmatic one. The fact that this structure is limited to the cases, when some part of the apatite has crystallized before the magnetite, lessens its importance in this respect very considerably. We also ought to remember that continuous transitions between this ore type and the normal, massive ones, exist. Finally, its geological mode of occurrence shows that the structure cannot possibly be a sedimentary one. We find this ore in abundance at Tuolluvaara, where the ore bodies are dikes cutting the porphyry, in the apatite dikes and in the spur projecting from the main mass of the Kiirunavaara ore in the porphyries at Grufingeniören. This spur is evidently to regard as an apophysis from the ore, and cannot have obtained its place through any kind of folding processes. If the »stratified» ore thus cannot have originated through sedimentation it is, however, not very easy to explain it from the magmatic point of view. Beside the difference of age between the two minerals one may be guided by the distribution of this ore type, as it generally occurs in places where one might expect to find fluidal

phenomena, and often passes into phases showing a fluidal inhomogeneity (see figs. 35 and 38). This ore type has therefore probably been formed in the following manner. In a magma consisting of magnetite and much apatite there crystallized first relatively large apatite crystals; during movements of the magma the latter massed themselves together into lumps which later on were rolled out into layers, between which the magnetite and the remaining apatite crystallized. Fig. 43 shows a case when no stratification has come into existence though the apatite has crystallized before the magnetite. This may depend on the fact, that no movements of the kind just mentioned have taken place.

The shape and the geological mode of occurrence of the Kiirunavaara and Luossavaara ores are unquestionably at first sight likely to confirm the opinion that there are present in them deposits of sedimentary origin. But these qualities are just as consistent with the supposition that they should be igneous beds, and the results of a closer examination of the foot wall contact, especially on Kiirunavaara, are greatly in favour of the magmatic theory. Especially ought to be remembered the local amphibolization of the wall rock, and the numerous dikes and veins of ore interweaving it. With regard to the ore of Tuolluvaara, the sedimentary theory is quite out of the question, there we have only to choose between the pneumatolytic[1] and the magmatic one, the latter surely being the correct one, judging from the characters of the ore in itself and especially on account of the analogy to the larger ore bodies of the region.

The correctness of the magmatic point of view is also borne out by a comparison between the ores on one side and the apatite dikes of the quartz-porphyry as well as the magnetite dikes of the same rock and of the Luossavaara syenite-porphyries on the other. In the quartz-porphyry we even find real small ore bodies which doubtless are magmatically formed.

The most important proofs of the correctness of the theory maintaining that the Kiirunavaara, Luossavaara and Tuolluvaara ores are of magmatic origin, are consequently:

I. *The minerals occurring in the ores are all such as are primary constituents of the igneous rocks of the region.*

II. *Some structural phenomena show that the ore mass has crystallized quite in the same way as a normal igneous rock. These*

[1] The word pneumatolytic — as a contrast to magmatic — is here used synonymous for »formed through reactions between gaseous compounds and others.»

phenomena are, among other things, trachytoidal flow-structure, skeleton forms of magnetite, ophitic distribution of augite.

III. *The geological mode of occurrence of the ores is best consistent with this explanation, this being especially the case of Tuolluvaara.*

IV. *In the porphyries of the region there occur dikes and schlieren of most evident magmatic origin, which in their composition and structure are closely similar to now one, now the other ore variety.*

As it has now been shown that the immense ore deposits at Kiruna are of magmatic origin we have to try to make out to some extent through what processes of magmatic differentiation they have originated. With this we leave, however, the certain basis, the nature and the causes of the magmatic differentiation being, in spite of all efforts made to find them out, still one of the most difficult questions in the science of petrography. But VOGT has shown that the study of the iron ores formed by magmatic differentiation may furnish interesting knowledge of the details of their mode of formation and also throw light upon the matter in general. Though the material present for such a discussion of the ores of the syenitic[1] rocks is by far much less plentiful than what has been at VOGT's disposal, such a treatment and a comparison between the different ore types may therefore be in its place here; all the more as »the syenitic ores» up to now scarcely have been a subject of such a discussion.

We are, however, first going to give a short survey of the magmatic ores of the basic rocks — those studied by VOGT, KEMP and others — and some deposits in granites which one lately has begun to regard as having the same genesis.

A classical exemple of an iron ore of magmatic origin is Taberg in the province of Småland, Sweden [64, 69]. It is a mass of titaniferous magnetite, containing also some basic plagioclase and dark silicates and occupying the centre of an intrusive body of a gabbroid rock (hyperite), the ore being connected with the normal phase of it by gradual transitions. Ores

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[1] The group of iron ores in question is most properly to be called by this name, though the accompanying rocks often have the composition of a quartz-syenite or of a relatively basic granite.

of similar mode of occurrence have been found in gabbro in many places, especially in Sweden, Norway and North America. If it is not strange that the gabbros, which generally have a high content of iron, may enclose segregations of ore, it seems to be rather peculiar, however, that the latter are common also in anorthosite, a rock usually quite poor in iron. In Sweden (Routivare), Norway (Ekersund—Soggendal and other places) and in North America (for instance Adirondacks and Laramie Range) there are enormous bodies of iron ore in this rock. They are often, contrary to the ores of the gabbros, very sharply defined towards the mother rock, and sometimes form real dikes. Nor do they enclose so many impure minerals as the latter, generally only some dark silicates or often spinel. There exist, however, all transitions between these two kinds of ore, just as between their mother rocks. The nepheline-syenite rocks may also carry iron ores, as is the case at Alnö (Sweden) and Sao Paolo (Brazil). These ores are sometimes very rich in apatite. In all these cases the ores are titaniferous, consisting of titaniferous magnetite or of ilmenite or, perhaps most often, of a mixture of the two, the former being usually prevalent. A distinguishing quality is the total absence of all pneumatolytic features, if one does not consider as such a feature the existence of apatite mentioned above. The insignificant ore field of Näsberget in the province of Västerbotten, Sweden, is therefore quite different from all these. The writer has made only a very hasty visit there and has examined microscopally some specimens collected on that occasion and some brought home before by Professor HÖGBOM. As it appeared, however, that there was present here an iron ore as a product of magmatic differentiation, but nevertheless carrying pneumatolytic minerals, the case ought to be shortly mentioned here. The rock seems to be a medium-grained diabase, but beside a basic plagioclase there also occurs, in the neighbourhood of the ore concentrations, subordinately a very finely cross-twinned feldspar with an index of refraction somewhat lower than that of the Canada balsam and very similar to the cross-twinned feldspar of our Kiruna rocks. There are also seen augite, hornblende, magnetite, allotriomorphic titanite and some apatite. The structure is often beautifully ophitic. The ore occurs as innumerable schlieren and lenses, varying in diameter from a few cm to some meters, now sharply defined, now passing into the rock. It consists of dense, bluish black magnetite, with much pyrite and some quartz. The microscopic examination shows the latter to be probably primary; it encloses

small tourmaline crystals, and many such crystals are also seen in the rock immediately at the contact with the ore.

Several authors have lately begun to regard certain iron ores occurring in granitic rocks as products of magmatic differentiation, especially some types of ore quite common in the Lofoten Islands, Norway. These ores consist of quartziferous magnetite (free from titanium) or hematite, or of magnetite accompanied by a »skarn»-like gangue. They occur chiefly as lenses in the granite. VOGT [75] regards them as formed in analogy to the above described titaniferous ores, while HJ. SJÖGREN [58] holds forth that they are sharply defined towards the granite and therefore surely have crystallized from aqueo-igneous solutions which have constituted a kind of pegmatites to the granite. (They are cut by normal pegmatite dikes.) SJÖGREN proposes the term »diamagmatic» for such phenomena, this word being synonymous to the term »pegmatite type» used by LEITH [36].

An explanation resembling the one given by SJÖGREN has before been alleged by NEWLAND [46, 47] concerning some of the Adirondack magnetite ores, as the fluorite-bearing ore of Palmer Hill, which passes into a fluorite-granite.

H. JOHANSSON [28, 29] regards all ores of the iron region of Central Sweden as products of magmatic differentiation. HJ. SJÖGREN [57] has after the publishing of JOHANSSON's work abandoned his former standpoint with regard to them, but he does not want to explain them quite in the same way as the Lofoten ores. He believes, however, that the apatite-bearing magnetites have crystallized under almost exclusively magmatic conditions.

As to the interpretation of the ores connected with syenitic rocks, the historical survey given might surely show plainly enough how the opinions generally stand in this question.

Ores of pneumatolytic origin cannot always be distinguished with certainty from the magmatic ones. Transitions between these two groups must of course exist, and it is very probable that an occurrence, that by one writer has been placed among the magmatic ones, by another may be counted among such as are pneumatolytically formed. As it has been shown in the above that the structure of the great ore bodies of the Kiruna region can be explained only by the assumption of a magmatic origin, it may seem unnecessary to involve the pneumatolytic iron ores in this discussion. Even this group has, however, its representatives in

the region in question, and in this very fact we might see a suggestion concerning the explanation of the nature of the process of differentiation having caused the formation of the main ores of the place.

The simplest case of iron ore depositiòn through pneumatolytic reactions is the formation of hematite through the decomposition of $FeCl_3$ by water, as happens at volcanos, for instance Vesuvius. This simple reaction, which is the same as the one, according to which DE LAUNAY supposed the Kiirunavaara ore to be formed, appears only seldom to give rise to any great quantities of ore. The most numerous and important pneumatolytic occurrences belong to the group contact deposits, i. e. are bound to the border between an intrusive and an older, usually sedimentary rock, generally limestone. Among the most thoroughly studied deposits of this kind ougth to be held forth the large ones of the Iron Springs district, Utah, which have been recently described by LEITH and HARDER [35]. LEITH refers these ores to the »pegmatite type».

When also, as has been emphasized by KLOCKMANN [33], such contact deposits now and then happen to be older than the igneous rocks associated with them, it is nevertheless quite indubitable that the greatest part of these ores have originated out of emanations from the igneous rock which have influenced upon the surrounding older rocks and most strongly when the latter have been composed of easily soluble substances, e. g. limestone. These emanations are supposed to have been gaseous compounds or hot watery solutions. Some writers do not say exactly how they suppose the iron to have appeared, but most of them seem to have in their minds the above mentioned reaction between ferric chloride and water, the newformed acid being neutralized by the lime. LEITH and HARDER (op. cit.) imagine that the magnetite at Iron Springs is formed through a similar reaction of ferrous chloride with water. In some cases one might also take for granted that the iron has existed in solution as carbonate.

Just as pegmatites pass on one hand into quartz veins of a wholly aqueous origin and on the other hand into igneous rocks, there are all transitions from these pneumatolytic contact deposits to ores of hydrothermal origin and to magmatic ones. Among the former we may mention the calcite-bearing magnetite veins at Nikolajewski Zawod [v. GORECKI, 15] and the siliceous hematite ores at Vaquerias, Hidalgo, Mexico, described by VILLARELLO and BÖSE [7]. Examples of transitions of the

second kind seem to be present at Iron Springs, represented by the magnetite veins within the andesite laccolite.

Among the magmatic ores ennumerated above, there are several which might be regarded as pneumatolytic ores of the non-contact type, as those of the Lofoten granite and of central Sweden, according to SJÖGREN, the Palmer Hill ore, according to NEWLAND, and the occurrence at Näsberget.

When trying to make out the nature of the process of differentiation having caused the origin of the Kiruna ores and similar deposits, the writer soon found that one must not pay *too* much regard to the results obtained by the study of the ore segregations in basic rocks. It is true that the main ores of the group in question are very similar to the latter, in the respect that they are composed of the usually first crystallizing components of the surrounding rocks. But we must also take into account the apatite dikes and the Rektor ores, and it is then evident that the ore group in question is different from the above mentioned one studied by VOGT, in showing some plainly pneumatolytic features.

Among all that has been written about the cause of magmatic differentiation, the writer wants to remind the reader only of ARRHENIUS's account of the physical and chemical influence of water upon the magma, especially applied to pneumatolytic phenomena [2], and VOGT's explanation of this matter [73.]

We are now going to return to our Kiruna ores, and to discuss first which may be their mother rock. A differentiation giving rise to huge bodies of iron ore implies a magma with a considerable content of iron.[1] That such magmas should exist among the syenitic rocks was denied for a long time, but their presence in Ural has been proved by HÖGBOM [24], and the writer has in the above described their considerable distribution in the Kiruna region. The abundance of magnetite is a pervading feature of all Kiruna rocks and attains its height in the magnetite-syenite-porphyry. With analysis No. XII before one's sight there is surely no denying the possibility of the segregation of iron ores from syenitic rocks. Even if the magnetite percentage were not higher than 20, a complete differentiation of a rock mass with an area of less than 1500000 square meters would result in an ore body of the size of the Kiirunavaara mass.

[1] It is true that the anorthosites are usually relatively poor in iron, but nevertheless contain large ore masses. But it is evident that a high content of iron in the mother magma must favour the formation of such ores.

The other product would evidently be an albite rock. The similarity to the anorthosites and their ores is noteworthy. When the mother magma is as poor in MgO as the rock of analysis No. XII, there is no reason for expecting a considerable percentage of ferromagnesian silicates in the ore. The writer does of course not mean that the Kiirunavaara ore should have originated through such a simple differentiation. Its content of dark silicates indicates moreover, that the mother magma has not been of purely magnetite-syenitic composition.

By their mode of occurrence the Kiirunavaara-Luossavaara ores seem to be most closely connected with their hanging wall rock, the quartz-porphyry. The rock areas occurring in them, which do not seem to be fragments detached from the foot wall, are on the other hand more similar to the older, syenitic rocks. It seems to be most probable that the differentiation of the ore material has taken place before or at the same time as the separation of the mother magma in one syenitic and one quartz-bearing phase.

Now arises the question of the cause and progress of the differentiation progress. Contrary to what is the case among the ores of the basic rocks, we have no deposits crystallized *in statu nascendi* at hand. Nowhere within the Kiruna region or outside it do we find the differentiation interrupted at such a stage, that the crystallized product gives any considerably information in this respect. Some hints might possibly be obtained only from the ore dikes and schlieren of the quartz-porphyry of Kiirunavaara and the sadly to say very little exposed ore-bearing porphyry immediately south of lake Syväjärvi. The magnetite-syenite-porphyry gives us but little information in this respect. We must therefore exclusively attend to the mineralogical composition of the ores and the characters of the smaller deposits, which must be of almost the same origin.

In the ores of the basic rocks, the common minerals usually enter in proportions according to how early they have begun to crystallize in the normal mother rock, the first crystallizing one being predominant. In the large Kiruna ores the case is on the whole the same. The magnetite and the apatite are generally among the first crystallizing minerals of a rock; the dark silicates, which generally have the place after them enter also in the ore in a smaller quantity than corresponds to their relations in the rocks to the just mentioned minerals. Nevertheless one cannot say that the ores are a concentration of the first crystallized minerals of the common mother magma of the ores and rocks at Kiruna. As a matter

of fact we see plainly in the latter, how the magnetite and the apatite, the two main constituents of the ore, are disposed to separate from the rest of the rock and are in solution longer than the latter. On the other hand we ought to remember that even feldspar, especially albite, often occurs in the same manner. It appears thus, that from the mineralogical composition of the main ores we cannot judge with certainty whether they have been the first crystallized part of the magma or have remained longer in solution and formed a separation product of pegmatitic nature. The absence of feldspar is quite as peculiar in both cases.

The presence of tourmaline seems to imply the second alternative, but from this phenomenon only it would not be judicious to draw a definite conclusion. If we take into account the small deposits of almost no economic value, as the dikes of apatite and of magnetite, the Rektor and Nokutusvaara ores etc., we find, however, a mineral association plainly proving what has been suggested by this typical pneumatolytic minerals occurring in the main ores. The tourmaline is here rather abundant locally, further on there are seen quartz, calcite and orthite; the occurrence of albite may perhaps also be regarded as a pneumatolytic character when in an otherwise basic rock. But more basic plagioclases and augite are not found at all, and hornblende is very rare. Also in their mode of occurrence these deposits show their genetic nature very plainly: they always form dike-shaped bodies and occur as a rule in a manner proving them to have crystallized only after the development of jointing planes in the porphyry. When taking also into account their association with quartz-hematite veins, one cannot doubt that these small deposits, in spite of their structure generally pointing at crystallization under magmatic conditions, genetically may be regarded as pegmatitic phenomena. When going still further and including the hematite ores of the region, we find the same characters even more pronounced. The iron is here deposited in the shape of hematite, quartz is the most important associated mineral, besides we find apatite, calcite, zircon[1] and orthite, the last mentioned one often in great quantity. The baryte is new and implies rather purely aqueous conditions. When also, as has been pointed out p. 191, these ores must be regarded as a product of the volcanic activity in this region, we

[1] The occurrence of zircon in the main ores and in the apatite dikes is as compatible with the magmatic as with the pneumatolytic point of view, but its occurring in the hematite ores in the described manner must surely indicate that these ores not are the result of a normal sedimentation.

dare not, however, from their characters draw any definite conclusions regarding the origin of the magnetite ores.

The ores of the Kiruna region constitute thus, with regard to the physico-chemical conditions at their formation, a rather well continuous series. The differences between the various ore types ought probably to be interpreted thus: the lower the crystallization temperature of the ores, the higher the content of »pneumatolytic» minerals and the more distinct appears their character as the last crystallizing part of the common parent magma of the rocks and the ores of the district. The main ores which are almost free from »pneumatolytic» substances — except the apatite — must have crystallized under quite magmatic conditions, equal to those of the rocks; the apatite dikes, though having magmatic structures, have in these regards been akin to pegmatites. The hematite ores are not igneous and perhaps not eruptive in a proper sense, though their deposition may be regarded as one of the last phases of the volcanic activity.

The ore thus represent the last crystallizing parts (i. e. the parts having the lowest temperature of crystallization) of the series, in which the differentiation of the original parent magma has resulted. In this rest, the bulk of the water and the mineralizers in a proper sense (e. g. compounds of boron) must have gathered, as is always the case. But why have iron and apatite gathered in this magma? In the case of the latter this is not so very strange, as it is very often found in a purely pneumatolytic association and is partly made up of halogens. As to the wandering of the iron one may ask the same question about several pneumatolytic deposits given an account of in the above. The matter is very simple in the cases when one can suppose that it has wandered in the shape of an association of halogens. But this cannot have been the case in Kiruna, as the enormous quantities of acid at their freeing surely ought to have left some trace behind. But in the wall rocks there is neither scapolite nor fluorite, topaze or any other new-formed halogen minerals. Nor is the halogen to be sought for in the apatite as the latter contains too little of it and also wanders as such in the magma, as has been shown by VOGT [72]. If one follows VOGT's application of ARRHENIUS's views and ascribes to the water a great importance in order to explain the differentiation process, it would seem probable that the tendency of the iron to occur only in compounds of oxygen might have been the cause of its having, in spite of the lack of halogen, gathered in this pegmatitic product.

The *mise en place* of the Kiirunavaara—Luossavaara ores is believed by the writer to have been as follows. After the solidification of the syenitic outflow, during the period of eruption of the syenite-porphyry dikes, there have taken place eruptions of magnetite, spreading out as somewhat irregular lava beds. These eruptions were followed by a comparatively slight fumarolic action. That only little water emanated is shown by the fact that the foot wall rocks are but little metamorphosed. The much complicated outlines of the feldspars in some rocks in the very wall may perhaps depend on a metamorphism due to hot waters, otherwise there are no signs of such a metamorphism. It is impossible to determine whether the ore beds are made up each of one or several eruptions, though the last-mentioned origin seems quite probable at least as regards Kiirunavaara.

As to this part of the problem, the writer thus agrees more with BÄCKSTRÖM than with for instance STUTZER.

Some reactions probably continued even after the eruption of the quartz-porphyry. This phenomenon, together with the existence of small ore bodies in this porphyry, makes it very probable that the eruption of the ores took place shortly before that of the rock in question. The whole time between the eruptions of the main porphyry beds seems to have been very short.

Even with regard to the mode of differentiation of the ore substances, the writer's views resemble those defended by BÄCKSTRÖM, and those which caused LEITH to establish the »pegmatite type.»

Some one might think, perhaps, that the writer, having this opinion of the genesis of the Kiruna ores, ought to call them pneumatolytic and not magmatic. With regard to the hematite ores the first name might perhaps be used to advantage, though the word hydrothermal, as must be acknowledged, gives a much more definite idea, but it is inappropriate even with regard to the apatite dike type and still more when applied to the main ores. For when the structure proves that the ore mass during the crystallization has been in the same state of aggregation as an (effusive) igneous rock at the same stage of evolution, the mode of formation must be called magmatic. The Kiruna ores must accordingly, in systems arranged on the basis of the mode of origin of the ores, be placed in the group of magmatic differentiation products. This group may perhaps be divided into two subsections, one comprehending segregations of the first crystallizing minerals (iron ores of the Taberg type, chromite ores, and

others), the other, the »pegmatite type», ores as last crystallizing part magmas (iron ores of the Kiruna type, pyrrhotite). But it is difficult to place such ores as the dike-forming titaniferous ones. That the iron ores of the acid rocks as a rule belong to the last mentioned type, seems to depend on the greater content of water and mineralizers in the acid magmas. This content facilitates a more thorough differentiation. LÖFSTRAND has evidently have a vague idea of such a distinction. The terms syngenetic and epigenetic will surely, concerning these iron ores, and those related to them, henceforth be left alone.[1]

As the Kiruna region gives an opportunity of examining different but mutually closely related ore types occurring in practically non-metamorphosed rocks, it may be rather interesting to make a survey of other iron ores of the same geological association and find out, in what degree their characters are in favour of or against the explanation adopted here.

In the first place we are going to examine some other deposits within the north Swedish »iron region».

At *Ekströmsberg*, the ore is very similar to that of Kiirunavaara and occurs between beds of quartz-bearing porphyry (presumably effusive), interstratified with subordinate syenite-porphyries. Remarkable is the occurrence of quartziferous hematite beds, whose relations to the magnetite mass and to the rocks not are very well known.

The ore field of *Mertainen* is in many respects rather similar to that of Tuolluvaara, but the country rock is there a basic syenite-porphyry containing numerous magnetite nodules surrounded by white rings. Both in hand specimens and under the microscope it is therefore very similar to some phases of the foot wall rocks of the Kiirunavaara-Luossavaara district. The rock fragments in the breccia are often highly (pneumatolytically) metamorphosed, sometimes carrying much scapolite. The larger ore masses do not form dikes as at Tuolluvaara, but irregular lumps.

At *Painirova*, a mixture of magnetite and apatite forms schlieren and anastomosing dike-like bodies in a syenite-porphyry, which is in part rich in magnetite. The mode of occurrence resembles the ore segregations in the quartz-porphyry of Kiirunavaara very much. The apatite occurs in

[1] As an example of the unsuitability of these terms for explaining the genetical nature of the Kiruna ores, ought to be pointed out that the latter on account of HÖGBOM's opinions have been placed among the syngenetic ores, while STUTZER has characterized them as epigenetic; both these different proceedings may be justified, and the difference between the opinions of the two writers is yet probably very slight, at least when comparing them on one side to for instance DE LAUNAY on the other.

large individuals, the ore thus forms a kind of apatite-magnetite-pegmatite. STUTZER [62] has in one slide of the wall rock found tourmaline in abundance, together with magnetite.

The ore of *Svappavaara* occurs in metamorphic rocks of a syenitic character. This deposit is in many respects similar to the others within the »Jukkasjärvi iron region», but differs from them by having a considerable content of calcite, most probably of primary nature. On the contacts there is sometimes seen a »skarn» of garnet, augite, apatite etc. Garnet also occurs here and there within the ore.

As to *Gellivare Malmberg* the writer begs to refer the readers to HÖGBOM's description [25].

Among the ore deposits of *central Sweden* there are many carrying much apatite, amid them the great ore field of *Grängesberg*, which may be geologically equal to the Kiruna ores. But as they are lying in metamorphic rocks and their mode of origin is not satisfactorily explained, they can give no information with regard to the Kiruna ores and we therefore pass over them here. We beg, however, to remind the readers of H. JOHANSSON's already mentioned view of the genesis of the iron ores of central Sweden which is based especially on detailed examinations at Grängesberg [27, 30]. Though JOHANSSON's opinion has not been universally approved as yet, it is surely, with reference to the apatite-bearing ores, embraced by many scientists.

In *northern Ural* there is a group of magnetite deposits, which are highly analogous to those of the north Swedish region. The accompanying, mainly syenitic rocks resemble, in their composition as well as in their structure, our syenite and porphyries. Also magnetite-syenitic phases occur, as has already been stated. The ores usually form schliere- or bed-like bodies within the syenitic rocks (*Blagodat*, *Wyssokaja*). Mineralogically they are sometimes, e. g. at *Lebiajaja*, characterized by an abundance of apatite, which occurs in about the same manner as in the Kiirunavaara ore. In the ore of Blagodat a quite fresh, very light red pyroxene occurs, and spinel was found by HÖGBOM [24]. The occurrence of these two minerals — especially the spinel — is a good reason for supposing the ore to be of magmatic origin. TSCHERNYSCHEW [63] and HÖGBOM [24] regard it as schlieren in the syenitic rocks, while LOEWINSON-LESSING [38] emphasizes the occurrence of »ore-breccia» (similar to that of the north Swedish ore fields) and seems to suppose that the ore represents a special intrusion, younger than these rocks. The last men-

tioned author regards [37] the ore of Wyssokaja as a contact deposit of the Banat type, probably older than all the syenitic rocks of the district TSCHERNYSCHEW and HÖGBOM, on the other hand, want to explain this deposit in analogy to Blagodat.

At *Magnitnaja* in southern Ural, the geological conditions seem to be more complicated and probably of quite another kind, according to the description given by MOROZEVICZ [45].

Some iron ores of *Mexico*, and among them the immense mass of the Cerro del Mercado at Durango, also seem to show important analogies to the Kiruna ores. They are, at least at Durango, associated with rhyolithes and quartz-bearing trachytes of a late Tertiary age [see FARRINGTON, 9]. The ore is massive hematite and contains on the whole very little impurities, but shows up to 0,8 per cent phosphorus. As no minute examinations are at hand, it is impossible to decide how far the similarities to the Kiruna ores extend. It seems to be rather possible, however, that even these ores are of magmatic origin. Their density and hardness are among other things in favour of this opinion. As they are so young and scarcely have been subjected to any very considerable metamorphism, one must regard these characters as primary, in which case the magmatic origin seems to be the only one possible.

LEITH [35] is of the opinion, however, that these deposits are very likely to be pneumatolytic deposits of the same type as the Iron Springs ores studied by him. At Durango there really are proofs of strong pneumatolytic actions, as there occur phenakite, topaze, apatite and fluorite. Some deposits are also reported to occur in grano-diorite (Las Truchas) or on the contact between this rock and limestone.

In their geological mode of occurrence the greatest part of all these ore deposits are rather similar to those of the Kiruna region. With regard to mineralogical composition and structure there are few features implying any great difference. The occurrence of corundum at Gellivare Malmberg and of spinel at Blagodat are similarities to the ores of the basic rocks. These minerals, of which the last mentioned one is a strong proof of the igneous origin of the ore, are neither against, nor in favour of the explanation of the differentiation process given here. Their chemical similarity to respectively hematite and magnetite is worth noticing. More remarkable is the high calcite content of the Svappavaara ore. In its mode of occurrence and also in many other characteristic features this ore deposit resembles the rest of the family, not least Kiirunavaara, so

much, that the theory trying to explain the latter ought to give some clue to the explanation of Svappavaara. To the writer it seems to be quite probable that Svappavaara, even if the calcite is primary, should be explained according to the theory expounded here. In the first place we ought to remember that calcite at sufficient pressure, under certain chemical conditions, can crystallize from a magma, as is shown expecially by the limestones and calcite-bearing titanomagnetite ores of the Alnö nepheline-syenite. The same mineral can moreover be deposited from hot solutions emanating from a cooling magma. There evidently exists nothing to prevent the mixture of magnetite, hematite, calcite and apatite constituting the Svappavaara ore from having crystallized at an altogether »magmatic» temperature, if only the pressure has been strong enough. If so has not been the case one mus t have recourse to the explanation that the same mixture has been a hot solution, a pegmatitic rest. In any case the association of calcite with the ore minerals indicates that even in the case of Svappavaara the »pneumatolytic substances» (for instance CO_2) at the differentiation have moved in association with the iron, the case thus being a confirmation of the already stated view of the nature and progress of the differentiation.

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